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July 1994

US Army Corps
of Engineers
Waterways Experiment
Station

Demonstration Erosion Control Project Monitoring Program

Fiscal Year 1993 Report

Volume V: Appendix D
Comparison of Distributive Versus Lumped Rainfall-Runoff Modeling Techniques

by Billy E. Johnson

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Prepared for U.S. Army Engineer District, Vicksburg

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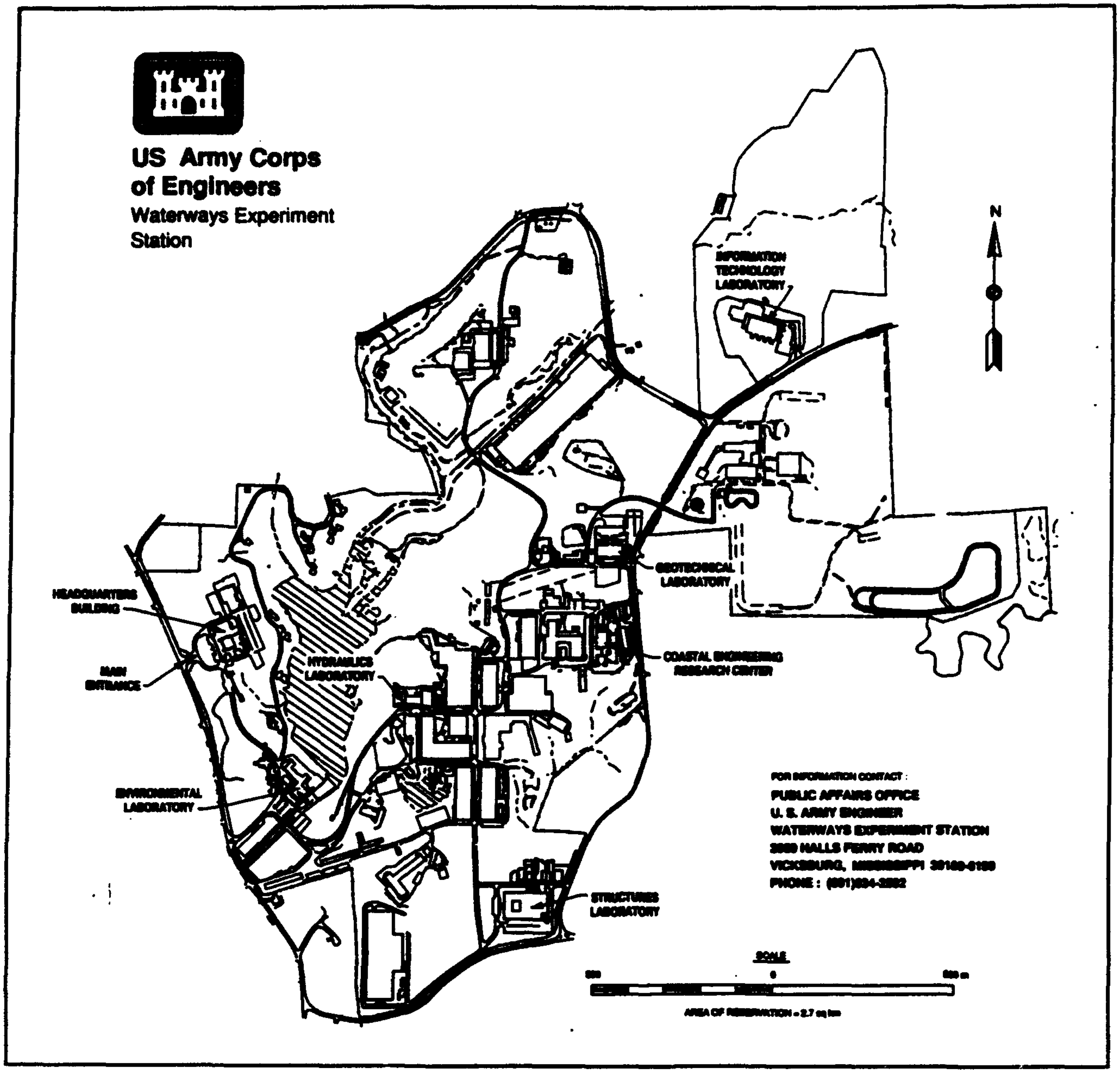

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This thesis was submitted to Memphis State University, Memphis, TN, in partial fulfillment of the requirements for the degree of Master of Science.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I - INTRODUCTION

Past History of Hydrologic Modeling Efforts in North Mississippi

In the past, the Agricultural Research Service (ARS), the U.S. Army Corps of Engineers (COE), and the Soil Conservation Service (SCS) have worked to stabilize stream bank erosion in North Mississippi. In this effort, there have been many structures built which required the estimation of a design flow. In the design of these structures, various hydrologic models have been used. In some cases, different methods or models were used for the same watershed. In those cases, a significant difference in computed design flows usually resulted. The question then is "which method computes the flow that is closest to the correct flow?". Two examples of studies where different methods have been applied are presented below. The discussion focuses on a description of the watersheds, the procedures used on each watershed, and the results from each procedure. As noted above, the primary purpose of the methods employed was to generate a peak design flow for stream bank erosion and/or grade control structures.

Long Creek Watershed. The Long Creek watershed is located in the southwestern part of Panola County in north-central Mississippi (Figure 1.1).[1] The watershed covers an area of approximately 86 sq. miles (55,074 acres) and is rectangular in shape, approximately 13 miles long and 8 miles wide. The

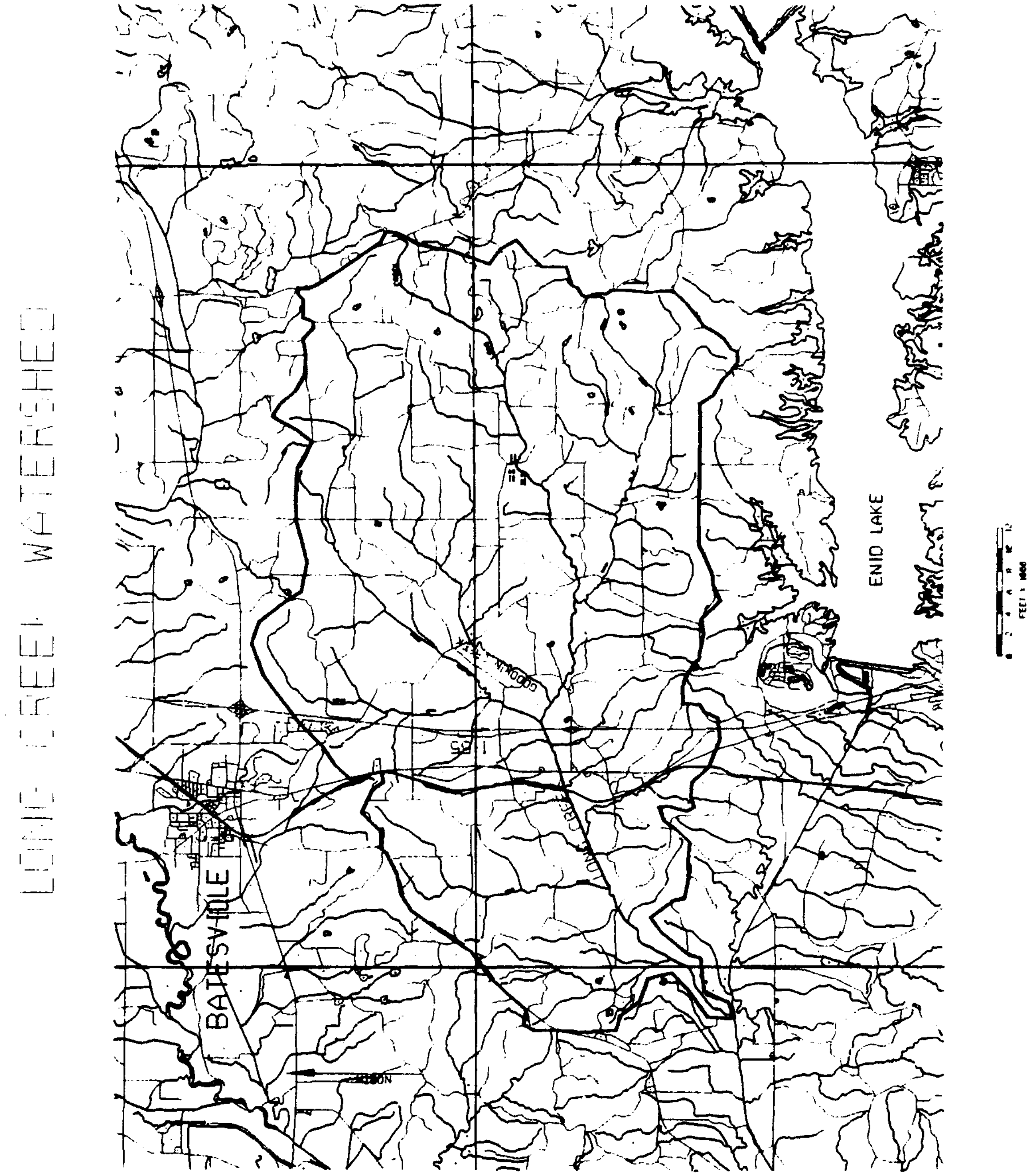

Figure 1.1 - Long Creek Watershed Map

Long Creek basin drains into the Yocona River downstream of Enid Reservoir and is a part of the Yazoo River Basin. The relief of the watershed is 314 feet with the lowest point at 170.5 feet NGVD and the highest point at 485 feet NGVD.[1]

Long Creek watershed lies in a subtropical region characterized by mild, humid winters and long, hot, and humid summers. The weather in the region is controlled by its proximity to the Gulf of Mexico and prevailing southerly winds. The wet seasons are winter and spring with prolonged, low intensity rains. During the summer and fall, rain falls mostly as thunderstorms with intense rainfall, short duration, and limited aerial coverage. Hurricane force winds do not affect the region but heavy rainfall from tropical storms do occur occasionally in the summer and fall months.[1]

There are three National Weather Service Stations in the vicinity of the Long Creek watershed: Batesville, Enid Dam, and Water Valley. Average annual precipitation for these three stations is given in Table 1.1. This study was conducted in 1987 and as such the data presented here is only accurate up to that point in time. The driest year of record was 1981 with the wettest year being 1973. In 1981, the rainfall amounts (in inches) at the three stations were: Batesville - 38.83, Enid Dam - 34.61, and Water Valley - 34.62. In 1973, the rainfall amounts (in inches) were: Batesville - 75.35, Enid Dam - 73.96, and Water Valley - 80.89.

Table 1.1 Average Annual Precipitation at Stations in the Long Creek Watershed Vicinity.[1]

Station	Average Annual Precipitation (inches)	Period of Record
Batesville	53.53	1949 - 1986
Enid Dam	51.79	1949 - 1986
Water Valley	54.25	1949 - 1986

In the Long Creek watershed, there were twelve streams used in the hydrologic analysis. Table 1.2 lists the streams and the drainage area of each.

Table 1.2 Drainage Areas for the Streams Studied in the Long Creek Watershed.

Stream Name	Drainage Area	
	Acres	Sq. Miles
Peters Creek	55,074	86.05
Bobo Bayou	3,940	6.16
Pope Tributary	1,916	2.99
Long Creek	39,265	61.35
Johnson Creek	13,257	20.71
Hurt Creek	4,486	7.01
Goodwin Creek	5,489	8.58
Goodwin Creek Tributary No. 2	436	0.68
Goodwin Creek Tributary No. 3	878	1.37
Goodwin Creek Tributary No. 4	997	1.56
Goodwin Creek Tributary No. 4E	279	0.44
Caney Creek	9,221	14.41

For the above mentioned streams, there were three different hydrologic analyses performed. In 1966, taken from the Long Creek watershed report dated July 1987, the U.S. Army Corps of Engineers used the generalized peak flow frequency analysis procedure for Yazoo Hill area. This procedure was

developed by taking numerous observed discharge readings within the Yazoo Hill area and using least squares regression analysis to determine a relationship for peak flow as a function of the physiographic watershed parameters. By knowing the basin area, slope, and stream length, the peak flow for a specific frequency can be calculated.

In 1976, there was a Flood Frequency of Mississippi Streams analysis done by Colson and Hudson of the United States Geological Survey (USGS).[2] This method involved essentially the same regression analysis as the Yazoo Hill Area procedure except that data was taken over the whole state instead of just the Yazoo Hill area. Again, by knowing the basin area, slope, and stream length, the USGS equations can be used to calculate a peak flow for a given frequency.

In 1987, FTN Associates, Ltd. from Little Rock, Arkansas performed an HEC-1 study, for the Vicksburg District COE, using Snyder's Unit Hydrograph method for overland flow and the Muskingum channel routing routine. The Muskingum method requires three parameters for each channel reach. These parameters are the Muskingum K coefficient, the Muskingum X coefficient, and the number of routing subreaches within the channel reach. These parameters are best determined from recorded inflow and outflow data for the reach in question.[3] However since streamflow data is limited for the watersheds being modeled, other methods were used to estimate the parameters.

The Muskingum K coefficient is known as the storage coefficient and is the ratio of storage to discharge. It has the dimensions of time and can be estimated as the travel time of the flood wave through the reach. The only data available for estimating travel time were the channel length and slope determined from topographic maps, and estimates of channel size and roughness based on site visit observations. These data were used to estimate the velocity and hence the travel time through each reach.[3]

The Muskingum coefficient x has theoretical limits between 0.0 and 0.5 with a mean value near 0.2. For this study (FTN Associates Flood Frequency Analysis for Long Creek), the coefficient was set equal to 0.10 for all channel reaches to reflect the expected storage effects characteristic of this type of watershed.

Results from the three peak flow frequency methods are presented in Table 1.3 where USGS corresponds to the USGS Flood Frequency of Mississippi Streams analysis, COE corresponds to the Generalized Peak Flow Frequency for Yazoo Hill Area analysis, and HEC-1 corresponds to the Calibrated HEC-1 study performed by FTN Associates LTD.

Table 1.3 - Listing of Results from the Flood Frequency Analyses for Long Creek Watershed. (FTN Associates, LTD.)

Stream Location	Return Period (yr)	USGS (cfs)	COE (cfs)	HEC-1 (cfs)
Peters Creek	2	6,266	9,200	22,300
at Yocona River	5	10,975	13,200	29,000
D.A. = 86.05 mi^2	10	14,314	16,700	33,900
	25	20,137	23,500	39,400
	50	24,326	28,500	44,700
	100	31,759	35,000	49,900
Bobo Bayou	2	1,547	1,780	2,970
at Peters Creek	5	2,554	2,500	3,820
D.A. = 6.16 mi^2	10	3,273	3,200	4,390
	25	4,163	4,500	5,060
	50	4,983	5,500	5,700
	100	5,554	6,800	6,440
Pope Tributary	2	823	1,100	1,670
at Peters Creek	5	1,312	1,580	2,140
D.A. = 2.99 mi^2	10	1,659	2,000	2,460
	25	2,090	2,800	2,840
	50	2,484	3,400	3,170
	100	2,758	4,250	3,580
Long Creek	2	7,393	7,400	14,000
at Peters Creek	5	13,334	10,500	18,100
D.A. = 61.35 mi^2	10	17,828	13,500	21,100
	25	23,657	19,000	24,400
	50	29,157	23,000	27,600
	100	32,935	28,500	31,000
Johnson Creek	2	2,239	3,750	7,170
at Long Creek	5	3,761	5,300	9,270
D.A. = 20.72 mi^2	10	4,892	6,800	10,700
	25	6,410	9,500	12,400
	50	7,828	11,500	14,000
	100	8,776	14,300	16,000
Hurt Creek	2	1,150	1,880	3,260
at Johnson Creek	5	1,872	2,580	4,180
D.A. = 7.01 mi^2	10	2,393	3,400	4,840
	25	3,123	4,800	5,580
	50	3,743	5,800	6,250
	100	4,310	7,200	7,060

Table 1.3 - Continued

Stream Location	Return Period (yr)	USGS (cfs)	COE (cfs)	HEC-1 (cfs)
Goodwin Creek at Long Creek D.A. = 8.58 mi^2	2	1,356	2,150	3,510
	5	2,224	3,050	4,500
	10	2,851	3,900	5,140
	25	3,740	5,500	5,910
	50	4,484	6,000	6,630
	100	5,200	8,200	7,560
Goodwin Creek Tributary No. 2 at Goodwin Creek D.A. = 0.68 mi^2	2	244	430	558
	5	357	620	709
	10	431	790	808
	25	535	1,100	926
	50	617	1,350	1,030
	100	705	1,680	1,190
Goodwin Creek Tributary No. 3 at Goodwin Creek D.A. = 1.37 mi^2	2	346	670	916
	5	523	960	1,160
	10	645	1,220	1,340
	25	822	1,720	1,540
	50	961	2,100	1,710
	100	1,114	2,600	1,950
Goodwin Creek Tributary No. 4 at Goodwin Creek D.A. = 2.00 mi^2	2	457	740	1,320
	5	704	1,050	1,680
	10	877	1,320	1,930
	25	1,125	1,850	2,220
	50	1,323	2,250	2,460
	100	1,530	2,800	2,810
Goodwin Creek Tributary No. 4E at Goodwin Creek Tributary No. 4 D.A. = 0.44 mi^2	2	218	320	373
	5	315	440	474
	10	379	580	538
	25	455	810	617
	50	527	980	687
	100	571	1,220	800
Caney Creek at Long Creek D.A. = 14.40 mi^2	2	2,607	3,000	5,670
	5	4,457	4,200	7,290
	10	5,826	5,400	8,470
	25	7,537	7,600	9,790
	50	9,159	9,200	10,980
	100	10,202	11,500	12,410

Hickahala-Senatobia Creek Watershed. The Hickahala-Senatobia watershed is located approximately 30 miles south of Memphis, TN. in northwestern Mississippi. A general location map for the watershed is shown in Figure 1.2. Hickahala Creek is a tributary to the Coldwater River just upstream of Arkabutla Reservoir. The Hickahala Creek watershed is located in portions of Tate, Panola, and Marshall Counties and encompasses approximately 230 square miles. The largest urban area of the watershed, the city of Senatobia, is located near the confluence of Senatobia and Hickahala Creeks, approximately 6 miles upstream of the confluence of Hickahala Creek and the Coldwater River.[3]

As with the Long Creek watershed, there were three different hydrologic methods used to estimate design flows for the stream bank erosion and grade control structures in the watershed. These were a calibrated HEC-1 model using Synder's Unit Hydrograph method for overland flows and the Muskingum channel routing method, the USGS Flood Frequency method for Mississippi Streams, and the US COE Generalized Peak Flow Frequency method for Yazoo Hill Area.

The parameters used in the Muskingum routing, K and X, were obtained in a similar manner as in the Long Creek study. However for this watershed, X was estimated to be 0.15. Results are presented in Table 1.4.

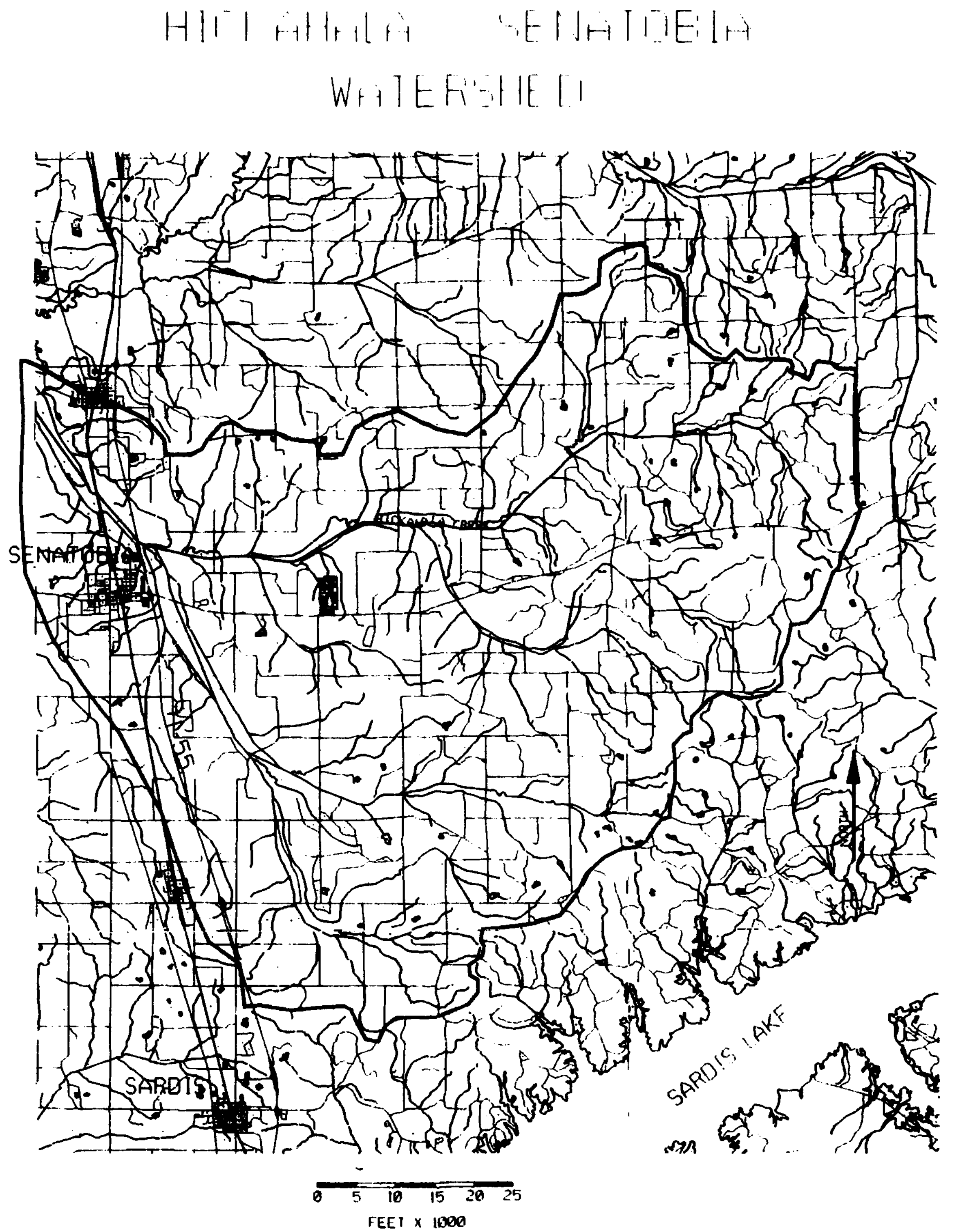

Figure 1.2 - Hickahala-Senatobia Creek Watershed Map

Table 1.4 - Peak Discharge Estimates within the Hickahala-Senatobia Creek Watershed (Simons, LI, & Associates, Inc.)

Stream Location	Return Period (yr)	USGS (cfs)	COE (cfs)	HEC-1 (cfs)
Hickahala Creek	2	2,630	3,600	2,646
Upstream of	5	4,484	5,100	4,073
Cathey Creek	10	5,860	6,500	5,301
D.A. = 19.24 mi^2	25	7,685	9,100	6,725
	50	9,360	11,100	8,263
	100	10,577	13,800	9,988
Hickahala Creek	2	3,721	5,100	5,260
Downstream of Beards	5	6,420	7,200	7,835
Creek and Cathey	10	8,420	9,300	10,193
Creek	25	11,231	13,000	12,734
D.A. = 36.82 mi^2	50	13,715	15,800	15,597
	100	15,803	19,400	18,789
Hickahala Creek	2	4,050	6,500	5,881
Downstream of	5	6,964	9,300	8,460
Whites Creek	10	9,121	11,900	10,850
D.A. = 50.00 mi^2	25	12,156	16,500	13,564
	50	14,895	20,000	16,575
	100	17,015	25,000	19,928
Hickahala Creek	2	6,580	10,000	11,129
Downstream of	5	11,545	14,500	15,311
Lick Creek	10	15,222	18,000	19,359
D.A. = 98.47 mi^2	25	20,400	25,800	23,849
	50	25,117	31,000	28,980
	100	28,679	38,500	34,687
Hickahala Creek	2	6,942	11,300	11,931
Downstream of	5	12,130	16,000	16,131
Basket Creek and	10	15,942	20,600	20,266
Thornton Creek	25	21,358	28,800	24,879
D.A. = 119.49 mi^2	50	26,286	35,000	30,165
	100	29,972	43,000	36,057
Hickahala Creek	2	6,672	11,500	11,996
Upstream of	5	11,573	16,600	16,208
Senatobia Creek	10	15,142	21,100	20,330
D.A. = 125.97 mi^2	25	20,274	29,800	24,951
	50	24,909	36,000	30,243
	100	28,418	44,500	36,133

Table 1.4 - Continued

Stream Location	Return Period (yr)	USGS (cfs)	COE (cfs)	HEC-1 (cfs)
Hickahala Creek at Coldwater River D.A. = 229.51 mi^2	2	9,115	17,000	28,310
	5	15,844	24,000	36,069
	10	20,650	31,000	43,774
	25	27,741	43,000	51,992
	50	34,031	52,500	60,637
	100	39,989	64,000	70,405
Cathey Creek at Hickahala Creek D.A. = 4.03 mi^2	2	700	1,300	933
	5	1,108	1,900	1,352
	10	1,397	2,400	1,741
	25	1,820	3,400	2,141
	50	2,163	4,050	2,582
	100	2,515	5,000	3,068
Beards Creek at Hickahala Creek D.A. = 10.94 mi^2	2	1,337	2,500	1,963
	5	2,176	3,500	2,935
	10	2,775	4,000	3,815
	25	3,723	6,400	4,745
	50	4,440	7,700	5,783
	100	5,366	9,300	6,934
Whites Creek at Hickahala Creek D.A. = 5.38 mi^2	2	856	1,600	1,120
	5	1,362	2,250	1,750
	10	1,719	2,800	2,246
	25	2,270	4,000	2,792
	50	2,688	4,800	3,398
	100	3,210	6,000	4,070
James Wolf Creek Downstream of Martin Dale Creek D.A. = 25.40 mi^2	2	2,779	4,250	3,638
	5	4,728	6,000	5,153
	10	6,178	7,700	6,537
	25	8,137	10,800	8,049
	50	9,944	13,200	9,728
	100	11,229	16,200	11,589
James Wolf Creek at Hickahala Creek D.A. = 38.90 mi^2	2	3,005	5,800	4,877
	5	5,069	8,000	6,526
	10	6,577	10,500	8,178
	25	8,808	14,500	9,968
	50	10,724	17,500	12,055
	100	12,458	21,500	14,385

Table 1.4 - Continued

Stream Location	Return Period (yr)	USGS (cfs)	COE (cfs)	HEC-1 (cfs)
Martin Dale Creek	2	846	1,550	1,256
at James Wolf Creek	5	1,351	2,200	1,721
D.A. = 4.94 mi^2	10	1,713	2,750	2,147
	25	2,233	3,800	2,584
	50	2,661	4,700	3,069
	100	3,085	5,400	3,535
Lick Creek at	2	594	1,100	912
Hickahala Creek	5	925	1,600	1,440
D.A. = 3.11 mi^2	10	1,155	2,000	1,847
	25	1,509	2,750	2,301
	50	1,773	3,400	2,735
	100	2,112	4,300	3,210
Basket Creek at	2	1,182	2,350	1,503
Hickahala Creek	5	1,914	3,300	2,159
D.A. = 9.71 mi^2	10	2,439	4,300	2,763
	25	3,250	5,900	3,432
	50	3,887	7,200	4,185
	100	4,625	9,000	5,020
Thornton Creek at	2	964	1,400	1,200
Hickahala Creek	5	1,547	1,950	1,783
D.A. = 4.65 mi^2	10	1,957	2,500	2,268
	25	2,535	3,500	2,812
	50	3,006	4,300	3,393
	100	3,487	5,200	4,034
Steammill Branch	2	549	960	692
at Thornton Creek	5	852	1,350	1,028
D.A. = 2.39 mi^2	10	1,062	1,750	1,341
	25	1,365	2,400	1,675
	50	1,606	2,900	2,024
	100	1,865	3,700	2,409
Billys Creek at	2	594	1,051	759
Hickahala Creek	5	928	1,550	1,198
D.A. = 2.93 mi^2	10	1,163	1,950	1,591
	25	1,505	2,650	1,992
	50	1,777	3,300	2,394
	100	2,072	4,200	2,836

Table 1.4 - Continued

Stream Location	Return Period (yr)	USGS (cfs)	COE (cfs)	HEC-1 (cfs)
Senatobia Creek	2	4,622	7,900	16,961
Downstream of	5	8,023	9,900	19,264
Mattic Creek	10	10,545	12,700	22,750
D.A. = 55.14 mi^2	25	14,113	17,700	26,202
	50	17,297	21,500	27,894
	100	19,892	26,500	31,255
Senatobia Creek at	2	3,770	7,650	16,706
Hickahala Creek	5	6,365	10,900	19,305
D.A. = 64.68 mi^2	10	8,231	13,900	22,755
	25	11,170	19,800	26,274
	50	13,567	23,800	27,839
	100	16,100	29,000	31,159
Tolbert Jones Creek	2	757	1,500	1,797
at Senatobia Creek	5	1,200	2,100	2,179
D.A. = 4.64 mi^2	10	1,514	2,700	2,572
	25	1,987	3,700	3,044
	50	2,358	4,600	3,476
	100	2,779	5,300	4,012
Mattic Creek at	2	2,798	4,100	9,422
Senatobia Creek	5	4,741	5,900	11,148
D.A. = 27.88 mi^2	10	6,159	7,500	13,171
	25	8,288	10,500	15,103
	50	10,033	13,000	16,121
	100	11,875	15,500	18,080
Nelson Creek at	2	1,486	2,800	4,808
Mattic Creek	5	2,433	4,200	5,679
D.A. = 14.23 mi^2	10	3,123	5,200	6,679
	25	4,136	7,600	7,860
	50	4,997	9,200	8,132
	100	5,786	11,500	9,158
Gravel Springs Cr.	2	511	1,100	1,224
at Senatobia Creek	5	790	1,550	1,523
D.A. = 2.84 mi^2	10	982	2,000	1,635
	25	1,288	2,750	1,899
	50	1,512	3,600	2,060
	100	1,815	4,200	2,637

Table 1.4 - Continued

Stream Location	Return Period (yr)	USGS (cfs)	COE (cfs)	HEC-1 (cfs)
West Ditch at	2	1,515	3,250	5,083
Hickahala Creek	5	2,469	4,600	5,824
D.A. = 16.84 mi^2	10	3,150	6,950	6,801
	25	4,267	8,250	7,872
	50	5,111	10,000	8,412
	100	6,203	12,000	9,518

From an inspection of Tables 1.3 and 1.4, a significant difference in the design flows computed by each method is observed. From Table 1.3, the % variance (ie, 100 x (Maximum Q / Minimum Q) for the 2 year frequency storm had a minimum of 171.1, a maximum of 355.9, and an average of 247.8. The variance for the 100 year frequency storm had a minimum of 115.8, a maximum of 238.3, and an average of 170.6. From Table 1.4, the % variance for the 2 year frequency storm had a minimum of 136.9, a maximum of 443.1, and an average of 220.9. The variance for the 100 year frequency storm had a minimum of 122.8, a maximum of 231.4, and an average of 173.4.

Purpose and Scope of Study

Since design flows must often be computed for ungaged watersheds, the discrepancy in the peak flows observed above causes concern about the relative accuracy of hydrologic methods/models currently used to simulate rainfall events. This concern was the stimulus for conducting the research

reported herein. In particular, the commonly employed SCS and Snyder's Unit Hydrograph methods of the HEC-1 computer program (one dimensional lumped models) have been compared to a recently developed two-dimensional distributed model from Colorado State University, CASC2D, to determine if this model that contains more spatial data can produce more reliable results when applied to ungaged basins.

Traditionally, the Snyder and SCS Unit Hydrograph methods are used to estimate the peak discharge for the purpose of designing channels, structures, etc. In using these methods, it is necessary to calibrate the lag time and infiltration parameters for each of the methods. Typically in using the Snyder method, initial and uniform loss rates are calibrated for different storm events. When using the SCS method, an SCS Curve Number relating landuse and soil type to loss rates is estimated.

The watershed chosen for this study was the Goodwin Creek Watershed. As illustrated in Figure 1.1, this watershed is a sub-watershed of the Long Creek Watershed. The Agricultural Research Service has been active for a number of years in gaging Goodwin Creek. These data provide an excellent opportunity for applying the hydrologic models noted above and to assess their performance on gaged and ungaged watershed scenarios, and to gain insight in choosing infiltration and other loss parameters for their application to North Mississippi Streams.

CHAPTER II - THEORETICAL ASPECTS AND METHODOLOGY APPLIED IN THE COMPUTER MODELS HEC-1 AND CASC2D

General Description/Model Philosophy

Both the HEC-1 and CASC2D computer models are designed to simulate the surface runoff response of a watershed to precipitation by representing the river basin as an interconnected system of hydrologic and hydraulic components. Each component models an aspect of the rainfall-runoff process within a smaller portion of the total watershed, commonly referred to as a sub-basin. A component may represent an overland flow entity, stream channel reach, reservoir, and etc. Representation of a component requires a set of parameters which specify the particular characteristics of the component and mathematical relations which describe the physical processes. The result of the modeling process is the computation of streamflow hydrographs at desired locations in the river basin.

A review of the users manuals for HEC-1 and CASC2D models shows that both models have the following comparable stream network components available for simulation purposes:

1. Land Surface or Sub-Basin Component
2. Channel Routing Component
3. Analysis Point and Hydrograph Combination

A sub-basin land surface runoff component is used to represent the movement of water overland to the stream channels. The input to this component is a precipitation

hyetograph. Precipitation excess is determined by subtracting infiltration and detention losses based upon a soil infiltration rate function. The rainfall and infiltration are assumed to be uniform over a sub-basin area. The resulting rainfall excesses are then routed by unit hydrograph, kinematic wave, or diffusive wave techniques to the outlet of the sub-basin producing a runoff hydrograph.

A reach routing component is used to represent flood wave movement in the river channels. The input to the component is an upstream hydrograph resulting from individual or combined contributions of sub-basin runoff and upstream reach routings. The hydrograph is routed to the downstream end of the river reach based upon the conveyance and storage characteristics of the channel.

A suitable combination of the sub-basin runoff and channel routing components can be used to represent the intricancies of a watershed stream network. The connectivity of the stream network components is implied by the order in which the data components are arranged. Simulation must always begin at the upper most sub-basin in a branch of the stream network. The simulation (succeeding data components) proceeds downstream until a confluence or a junction is reached. Before simulating below the confluence, all flows from drainage areas above that confluence must be computed and routed to the confluence. The flows are combined at the confluence and the combined streamflow hydrograph is routed downstream, etc.

HEC-1 Computer Model

The HEC-1, Flood Hydrograph Package, computer program has been available for over 25 years. It has been expanded and revised several times since the first version was published in October 1968 (version 2 - January 1973, version 3 - September 1981, and version 4 September 1990). A well documented users manual describes the concepts, methodologies, input requirements and output formats used in HEC-1. A variety of computational techniques or simulation options are available for most of the model components. For example, five different options of unit graph/kinematic wave techniques are available to transform rainfall excess into runoff. These include: (1) Input known unit graph; (2) Clark synthetic unit graph/time-area data; (3) Snyder synthetic unit graph/time-area data; (4) SCS dimensionless synthetic unit graph; and (5) Distributed runoff using kinematic wave or Muskingum-Cunge excess transformation. Precipitation data for an observed storm event can be supplied to the HEC-1 program by two methods: (1) Basin average precipitation; and (2) Weighted precipitation gages. There are three methods in HEC-1 for generating synthetic storm distributions: (1) Standard Project Storm; (2) Probable Maximum Precipitation; and (3) Synthetic Storms from Depth-Duration data. There are five methods available in HEC-1 for calculating the precipitation losses: (1) Initial and Uniform Loss Rate; (2) Exponential Loss Rate; (3) SCS Curve Number; (4) Holtan Loss Rate; and (5) Green and Ampt Infiltration

Function. The channel routing methods available in HEC-1 are based upon the continuity equation and some relationship between flow and storage or stage. The methods are: (1) Muskingum; (2) Muskingum-Cunge; (3) Kinematic Wave; (4) Modified Puls; and (5) Working R and D. In addition, HEC-1 has a level pool reservoir routing option available. HEC-1 also provides a powerful optimization technique for the estimation of some of the parameters when gaged precipitation and runoff data are available. By using this technique and regionalizing the results, rainfall-runoff parameters for ungaged areas can be estimated.

CASC2D Computer Model

The CASC2D, a two-dimensional watershed rainfall-runoff model, computer program was recently (1991) developed at Colorado State University. A user's manual explains the basics of a two-dimensional distributed rainfall-runoff model for the simulation and analysis of spatially and temporally varied rainstorms and basin characteristics. Unlike the HEC-1 model which has several simulation options available, the primary features of the CASC2D model include a two-dimensional diffusive wave overland flow routing component, the Green and Ampt Infiltration Scheme for a precipitation loss component, and a one-dimensional diffusive wave channel routing component. The model uses square grid elements, each of which is assumed homogeneous in all aspects. However, spatial

variations are allowed from one grid cell to another. For each time step, the existing overland surface depth, including that of rainfall depth over the time step, may be first diminished by the amount controlled by the infiltration capacity of the soil at that time. Then the remaining overland surface depth, if any, is processed through overland flow routing followed by channel routing. The backwater effects through channel networks are considered, as well as the disturbances produced when channels spill over to the floodplains.

The CASC2D model was developed as a tool to carry out research on effects of spatially varied watershed characteristics, spatially varied rainfall, and temporally varied rainfall due to moving rainstorms. The model can be used to determine the watershed time to equilibrium. An important potential application for the model is real-time flood forecasting, especially when coupled with an accurate updated GIS database and with remote data acquisition systems.

A more detailed description of the computational techniques and methodology used in the two computer models is included in the following sections. Only the options of HEC-1 that are equivalent for comparison purposes with the CASC2D model components will be discussed.

CASC2D Methodology

The discussion found in this section will be taken from the CASC2D User's Guide[6]. Physically-based, distributed

computer modeling of rainfall-runoff processes in watershed hydrology has gained considerable attention in recent years. Analysis of the processes controlling the watershed response typically requires solution of fundamental partial differential equations for overland flow and channel flow. However, analytical solutions have not been found except for very simplified cases. These solutions are further complicated by the temporal variations introduced by the transient nature of rainfall events and infiltration processes. The inability to obtain general analytical solutions has resulted in the adoption of various numerical schemes to simulate rainfall-runoff events using high speed computers.

CASC2D has been developed to determine the runoff hydrograph generated from any temporally-spatially varied rainfall event. The main objective of this model has been to provide a research tool for further analysis of temporal and spatial variations. However, it can also be used for real-time forecasting of rainfall-runoff events. The dynamic graphics capability of the model provides additional insights into the physical processes and their distribution in time and space.

Overland Flow Routing. Overland flow is generally a two-dimensional process which is controlled by spatial variations in slope, surface roughness, excess rainfall, and other parameters. Solutions for the full dynamic momentum equation for overland flow are complicated and generally unnecessary

for most watershed conditions. Hence a diffusive wave approximation is preferred.

As the overland flow drains into stream channels, one dimensional flow prevails. The diffusive wave equation for channel flow can predict the possible backwater effects in main channels and tributaries. As in the other watershed processes, the spatial variations in channel parameters must be accounted for in the model.

The Saint-Venant equations for continuity and momentum describe the mechanics of overland flow. The two-dimensional continuity equation in partial differential form reads as:

$$\frac{\partial h}{\partial t}+\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}=e \tag{2.1}$$

where

- h = surface flow depth
- q_x = unit flow in x-direction
- q_y = unit flow in y-direction
- e = excess rainfall equal to (i-f)
- i = rainfall intensity
- f = infiltration rate
- x,y = cartesian spatial coordinates
- t = time

The momentum equation in the x and y directions may be derived by equating the net forces per unit mass in each direction to the acceleration of flow in the same direction. The two-dimensional form of the equations of motion are:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=g[S_{ox}-S_{fx}-\frac{\partial h}{\partial x}] \tag{2.2a}$$

where

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=g[S_{oy}-S_{fy}-\frac{\partial h}{\partial y}] \qquad (2.2b)$$

u,v = average velocities in x and y direction respectively
S_{ox}, S_{oy} = bed slopes in x and y direction respectively
S_{fx}, S_{fy} = friction slopes in x and y direction respectively
g = acceleration due to gravity

The right hand side of the momentum equations describes the net forces along the x and y directions while the left hand side represents the local and convective acceleration terms.

In simplifying the momentum equations, the kinematic wave approximation assumes that all terms, except the bed slope and the friction slope, are negligible. This assumption, which is particularly valid for steep bed slopes, has been the basis for many rainfall-runoff models. However, a kinematic wave can not predict backwater effects due to downstream disturbances that may be important when simulating floods. On the other hand, a diffusive wave model can simulate backwater effects and is considered to be applicable for overland flow over rough surfaces as well as for channel flows. The momentum equation based on the diffusive wave approximation reduces to:

$$S_{fx}=S_{ox}-\frac{\partial h}{\partial x} \qquad (2.3)$$

From the three equations of continuity and momentum, five hydraulic variables need to be determined. Therefore a resistance law should be established to relate flow rate to depth and to other parameters. A general depth-discharge relationship may be written, in the x-direction for example,

as:

$$q_x = a_x h^b \tag{2.4}$$

where a_x and b are parameters which depend on flow regime; ie, laminar or turbulent. For laminar flow in the x-direction, the value for b is taken to be 3, and the following expression gives a_x:

$$a_x = \left(\frac{8g}{K\nu}\right) S_{fx} \tag{2.5}$$

where

K = resistance coefficient
v = kinematic viscosity

Similarly, for turbulent flow over a rough boundary, the Manning empirical resistance equation is used. Thus, b is equal to 5/3 and a_x is computed from the following expression:

$$a_x = \frac{S_{fx}^{\;0.5}}{n} \tag{2.6}$$

where

n = Manning's roughness coefficient

Rainfall Distribution. In CASC2D, rainfall was analyzed using an interpolation scheme based on the inverse distances squared. This scheme approximates the distribution of rainfall intensity over the watershed:

$$i^t(j,k) = \frac{\sum_{m=1}^{NRG} \frac{t_m^t(j_{rg}, k_{rg})}{d_m^2}}{\sum_{m=1}^{NRG} \frac{1}{d_m^2}} \qquad (2.7)$$

where

$i^t(j,k)$ = rainfall intensity in element (j,k) at time t.
$i^t(j_{rg},k_{rg})$ = rainfall intensity recorded by rainfall gages located at (j_{rg},k_{rg}) at time t.
d_m = distance from element (j,k) to rainfall gage located at (j_{rg},k_{rg}).
NRG = Total number of rainfall gages.

If no raingage data is available, rainfall is assumed to be uniform over the watershed.

Precipitation Loss. The first step in simulating a rainfall-runoff event on a watershed is to determine the excess rainfall. An infiltration scheme must accommodate both spatial variations due to soil texture changes, and temporal variations due to the time-variant nature of both rainfall and soil infiltration capacity. Additionally, the fact that rainfall history affects the infiltration rate at the present time has to be accounted for in the infiltration scheme. Ideally, the scheme should also rely on physically measurable soil infiltration parameters. The Green-Ampt infiltration equation adequately satisfies these requirements and is therefore well-suited for distributed watershed modeling.

The Green-Ampt infiltration scheme has gained considerable attention in the past decade, partially due to

the ever growing trend towards physically-based hydrologic modeling. The parameters of the Green-Ampt equation are based on the physical characteristics of the soil and therefore can be determined by field measurements or experiments. The Green-Ampt equation may be written as:

$$f=K_s[1+\frac{H_f M_d}{F}] \tag{2.8}$$

where

f = infiltration rate
K_s = hydraulic conductivity at normal saturation
H_f = capillary pressure head at the wetting front
M_d = soil moisture deficit equal to (O_c-O_i)
O_c = effective porosity equal to $(P-O_r)$
P = total soil porosity
O_r = residual saturation
O_i = initial soil moisture content
F = total infiltration depth

The head due to surface depth has been neglected as H_f easily overpowers shallow overland depth. Rawls[8] et al. (1983) provided sets of average values of total porosity, effective porosity, capillary pressure head, and hydraulic conductivity based on soil texture class (see Table 2.1).

Channel Routing. A one-dimensional channel routing technique, based on diffusive wave similar in principal to the overland flow routing, has been formulated in the model. For each time step, infiltration and overland flow routing are processed. This determines the net rate of overland flow pouring into the channel elements. Each individual channel, with constant properties, is routed towards junctions, if any, and ultimately towards the watershed outlet. Prior to the

Table 2.1 - Green-Ampt Parameters Based on Soil Texture

Soil Texture	Total Porosity	Effective Porosity	Wetted Front Capillary Head (cm)	Hydraulic Conductivity (cm/h)
Sand	0.437	0.417	4.95	11.78
Loamy Sand	0.437	0.401	6.13	2.99
Sandy Loam	0.453	0.412	11.01	1.09
Loam	0.463	0.434	8.89	0.34
Silt Loam	0.501	0.486	16.68	0.65
Sandy Clay-Loam	0.398	0.330	21.85	0.15
Clay Loam	0.464	0.309	20.88	0.10
Silty Clay-Loam	0.471	0.432	27.30	0.10
Sandy Clay	0.430	0.321	23.90	0.06
Silty Clay	0.479	0.423	29.22	0.05
Clay	0.475	0.385	31.63	0.03

Source : Green and Ampt parameters (CASC2D User's Manual)

model execution, all channels must be ordered with respect to variations in width, depth, and roughness. Any given channel path, identified by a series of elements through which it passes, must have a constant width, depth, and roughness.

The channel cross section is assumed to be rectangular, and, if straight, it lies in the middle of the square channel element. If the channel changes direction within a certain element, it runs from the middle of the entering side to the center of the element and then to the middle of the exiting

side.

In special cases, the channel may flow over into the floodplain, in which case the floodplain will be treated as part of the overland plain. Therefore, for each channel element, there can be channel flow restricted to the channel width and an overland flow when overflow from the channel occurs.

Backwater effects can be properly handled, even at the junctions of tributary channels. In the model formulation, the channel cross section is not subject to infiltration, which is likely to be negligible compared to the flow rate in the channel. However, any overland flow running toward the channel, channel overflow, and any specified detention storage all remain subject to infiltration.

A one-dimensional diffusive channel flow equation has been incorporated into the model. The governing equations are similar to those of overland flow except for a finite width. The one dimensional equation of continuity reads as follows:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=q_1 \qquad (2.9)$$

where

A = channel flow cross section
Q = total discharge in the channel
q_1 = lateral inflow rate per unit length, into or out of the channel.

Most cases of channel flow occur in the turbulent flow regime. The following equation represents the application of

Manning's resistance equation to channel flow.

$$Q=\frac{1}{n}AR^{2/3}S_f^{1/2} \tag{2.10}$$

where

R = hydraulic radius
S_f = friction slope

HEC-1 Methodology

Overland Flow Routing - SCS Unit Hydrograph. A method developed by the Soil Conservation Service for constructing synthetic unit hydrographs is based on a dimensionless hydrograph (Figure 2.1). This dimensionless graph is the result of an analysis of a large number of natural unit hydrographs from a wide range in size and geographic locations. The method requires only the determination of the time to peak (Equation 2.11), the peak discharge (Equations 2.12a and 2.12b), and Figure 2.1[4]. Parameters t_p and Q_p are computed as follows.

$$t_p=\frac{D}{2}+t_l \tag{2.11}$$

where

t_p = the time from the beginning of rainfall to peak discharge (hours)
D = the duration of rainfall (hours). $D=0.133*t_c$ where t_c is the time of concentration.
t_l = the lag time from the centroid of rainfall to peak discharge (hours).

and

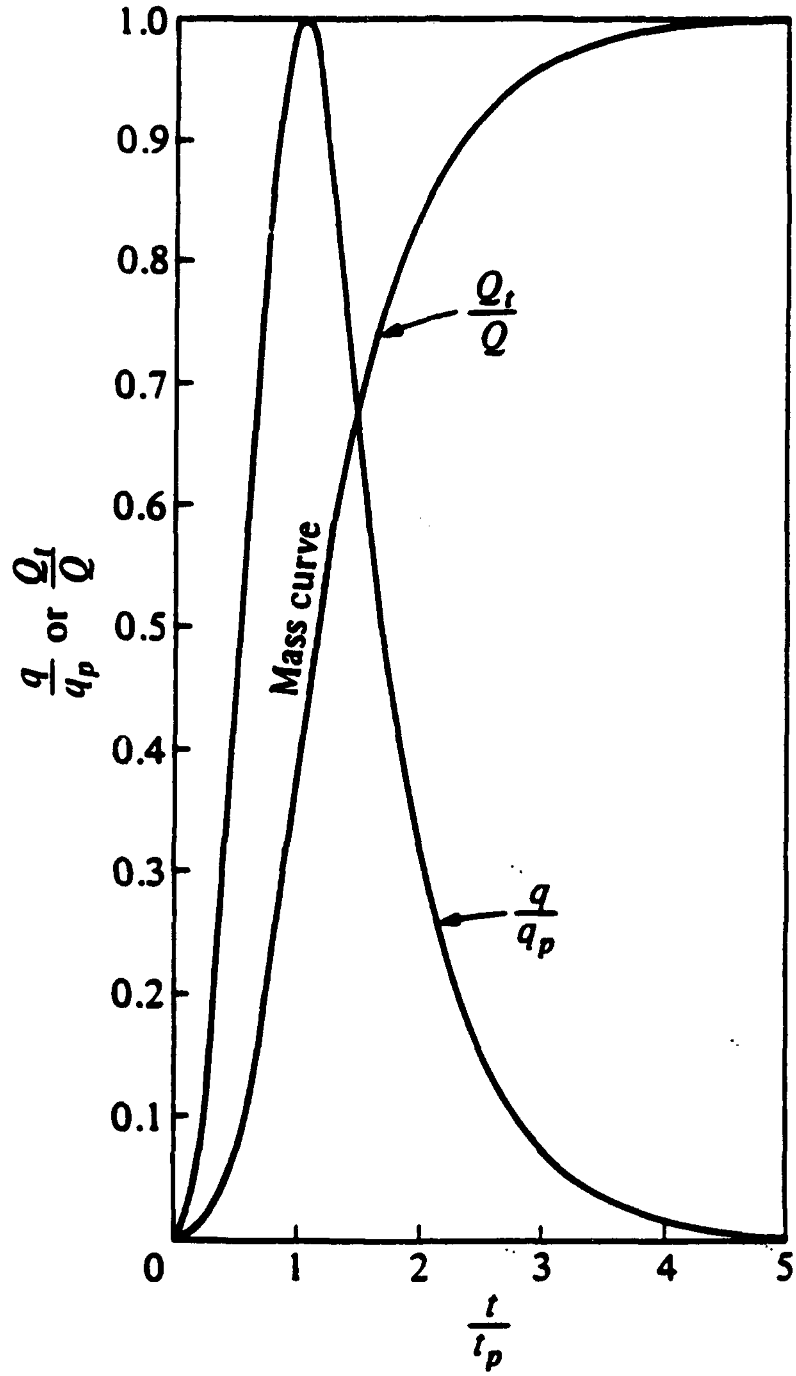

Figure 2.1 - Dimensionless unit hydrograph and mass curve. (After V. Mockus, "Use of Storm and Watershed Characteristics in Synthetic Hydrograph Analysis and Application," U.S. Soil Conservation Service, 1957.)

$$Q_p = \frac{KA}{t_p} \tag{2.12a}$$

$$K = \frac{1290.6}{1+H} \tag{2.12b}$$

where

Q_p = peak discharge (cfs)
A = drainage area (mi^2)
t_p = the time to peak (hours)
H = ratio of hydrograph recession time (i.e., Falling Limb) to period of rise.

This constant (H) should be determined for a particular watershed. H may be computed for a particular stream by using recorded hydrographs. Analyses by SCS have resulted in their adoption of H=1.67 (i.e., K=484) as a general average value for ungaged watersheds.[9] A K value of 484 reflects a unit hydrograph that has 3/8 of its area under the rising limb. For mountainous watersheds, the fraction could be expected to be greater than 3/8, and therefore the value of K may be 600 or higher (maximum K=1300). For flat, swampy areas, the value of K may be on the order of 300.

Overland Flow Routing - Snyder Unit Hydrograph. A common technique employed by the U.S. Army Corps of Engineers is based on methods developed by Snyder and expanded by Taylor and Schwarz.[4] Unfortunately, it does not provide a simple method of constructing the entire time distribution of the discharge hydrograph but allows computation of lag time, unit hydrograph duration, peak discharge, and hydrograph time

widths at 50 and 75 percent of peak flow. Using these points, a sketch of the unit hydrograph is obtained and checked to see if it contains 1 inch of direct runoff.[4]

Snyder's method of synthetic unit hydrographs relies upon correlation of the dependent variables of lag time and peak discharge with various physiographic watershed characteristics. A lag time relationship derived by Snyder for watersheds from 10 to 10,000 mi^2 located in the Appalachian Highlands is given as:

$$t_l = C_t (L L_{ca})^{0.3} \qquad (2.13)$$

where

t_l = the lag time (hours)
C_t = the coefficient representing variations of watershed slopes and storage.
L = length of the main stream channel (miles) from the outlet to the divide.
L_{ca} = length along the main channel to a point nearest the watershed centroid (miles).

It is assumed that lag time is a constant for a watershed that is uninfluenced by variations in rainfall intensities or similar factors. The use of L_{ca} accounts for the watershed shape, and C_t takes care of wide variations in topography, from plains to mountainous regions. Values of C_t for Snyder's original Appalachian study ranged from 1.8 to 2.2 with an average of about 2.0. The coefficient C_t accounts for variations in slope and storage and did not vary greatly for the Appalachian study areas. Steeper slopes tend to generate lower values of C_t. Extremes of C_t values of 0.4 has been noted

in Southern California and 8.0 along the Gulf of Mexico. When snow pack accumulations influence peak discharge, values of C_t will be between one-sixth to one-third of Snyder's original values.[4] The duration of rainfall for Snyder's synthetic unit hydrograph development is a function of lag time as shown by:

$$t_r = \frac{t_l}{5.5} \tag{2.14}$$

where

t_r = duration of the unit rainfall excess (hours).
t_l = the lag time from the centroid of unit rainfall excess to the peak of the unit hydrograph.

This synthetic technique (i.e., use of equations 2.13 and 2.14) always results in an initial unit hydrograph duration equal to $t_l/5.5$. However, since changes in lag time do occur with changes in duration of the excess rainfall, the following equation was developed to allow lag time and peak discharge adjustments for other unit hydrograph durations.[4]

$$t_{lR} = t_l + 0.25(t_R - t_r) \tag{2.15}$$

where

t_{lR} = the adjusted lag time (hours)
t_l = the original lag time (hours)
t_R = the desired unit hydrograph duration (hours)
t_r = the original unit hydrograph duration = $t_l/5.5$ (hours)

If one assumes a given duration rainfall produces 1 inch of direct runoff, the outflow volume is some relatively constant percentage of inflow volume, and a simplified approximation of outflow volume is $t_l * Q_p$, then the equation for peak flow can be written as:[4]

$$Q_p = \frac{640 C_p A}{t_l} \qquad (2.16)$$

where

Q_p = peak discharge (cfs)
C_p = the coefficient accounting for flood wave and channel storage conditions. It is a function of lag time, duration of runoff producing rain, effective area contributing to peak flow and drainage area.
A = watershed size (square miles)
t_l = the lag time (hours)

Both Snyder's coefficients, C_t and C_p, should be calibrated. Values for C_p range from 0.4 to 0.8 and generally indicate retention or storage capacity of the watershed. Larger values of C_p are generally associated with smaller values of C_t.[4]

The time base of a synthetic unit hydrograph by Snyder's method is:

$$T = 3 + \frac{t_l}{8} \qquad (2.17)$$

where

T = the base time of the synthetic unit hydrograph (days).
t_l = the lag time (hours).

Equation 2.17 gives reasonable estimates for large watersheds, but will produce excessively large values for smaller areas. A general rule of thumb for small areas is to use three to five times the time to peak as a base value when sketching a unit hydrograph.[4]

The Snyder method does not produce the complete unit hydrograph required by HEC-1. Thus, HEC-1 uses the Clark method to affect a Snyder unit graph. The Clark method (1945) requires three parameters to calculate a unit hydrograph: TC, the time of concentration for the basin, R, a storage coefficient, and a time-area curve. A time-area curve defines the cumulative area of the watershed contributing runoff to the subbasin outlet as a function of time (expressed as a proportion of TC).[5]

In the case that a time area curve is not supplied, HEC-1 utilizes a dimensionless time-area curve:[5]

for $0 <= T < 0.5$

$$AI=1.414T^{1.5} \tag{2.18}$$

for $0.5 < T < 1.0$

$$1-AI=1.414(1-T)^{1.5} \tag{2.19}$$

where AI is the cumulative area as a fraction of the total subbasin area and T is the fraction of time of concentration. The ordinates of the time-area curve are converted to volume of runoff per second for unit excess and interpolated to the given time interval. The resulting translation hydrograph is then routed through a linear reservoir to simulate the storage effects of the basin; and the resulting unit hydrograph for instantaneous excess is averaged to produce the hydrograph for unit excess occurring in the given time interval.[5]

The linear reservoir routing is accomplished using the general equation:[5]

$$Q(2)=CA\times I+CB\times Q(1) \tag{2.20}$$

The routing coefficients are calculated from:[5]

$$CA=\frac{\Delta t}{R+0.5\Delta t} \tag{2.21}$$

$$CB=1-CA \tag{2.22}$$

$$QUNGR=0.5[Q(1)+Q(2)] \tag{2.23}$$

where Q(2) is the instantaneous flow at the end of the period, Q(1) is the instantaneous flow at the beginning of the period, I is the ordinate of the translation hydrograph, (Δt) is the computation time interval in hours (also duration of unit excess), R is the basin storage factor in hours, and QUNGR is the unit hydrograph ordinates at the end of the computation interval. The computation of the unit hydrograph ordinates is terminated when its volume exceeds 0.995 inches or 150 ordinates, whichever comes first.[5]

The initial Clark parameters are estimated from the given Snyder's parameters, T_p and C_p. A unit hydrograph is computed using Clark's method and Snyder parameters are computed from the resulting unit graph by the following equations:[5]

$$CPTMP=QMAX\left[\frac{T_{peak}-0.5(\Delta t)}{C\times A}\right] \tag{2.24}$$

$$ALAG=1.048(T_{peak}-0.75(\Delta t)) \tag{2.25}$$

where CPTMP is Snyder's C_p for the computed unit hydrograph,

QMAX is the maximum ordinate of the unit hydrograph, T_{peak} is the time when QMAX occurs, in hours, (Δt) is the duration of excess, in hours, A is the subbasin area in square miles, C is a conversion factor, and ALAG is Snyder's standard Lag T_l for the computed unit hydrograph. Snyder's standard Lag is for a unit hydrograph which has a duration of excess equal to $T_l/5.5$. The coefficient, 1.048, in equation 2.25, results from converting the duration to the given time interval.[5]

Clark's TC and R are adjusted to compensate for differences between values of T_l and C_p calculated by Equations 2.24 and 2.25 and the given values. A new unit hydrograph is computed using these adjusted values. This procedure continues through 20 iterations or until the differences between computed and given values of T_l and C_p are less than one percent of the given values.[5]

Rainfall Distribution. The rainfall data was analyzed by using a weighted gage scheme. The temporal pattern for distribution of the storm-total precipitation is computed as a weighted average of temporal distributions from the recording station:

$$PRCP(I) = \frac{\Sigma PRCP(I,J) * WTR(J)}{\Sigma WTR(J)} \qquad (2.26)$$

where PRCP(I) is the basin-average precipitation for the I^{th} time interval, PRCPR(I,J) is the recording station precipitation for the I^{th} time interval, and WTR(J) is the

relative weight for gage J.

Precipitation Loss. The Green and Ampt infiltration function was implemented for both synthetic HEC-1 models (ie, Snyder's and SCS unit hydrograph techniques) in order to be comparable with CASC2D. The Green and Ampt infiltration function is combined with an initial abstraction to compute rainfall losses. The initial abstraction is satisfied prior to rainfall infiltration as follows:[5]

for P(t) <= IA T > 0

$$r(t)=0 \tag{2.27}$$

for P(t) > IA T > 0

$$r(t)=r_o(t) \tag{2.28}$$

where P(t) is the cumulative precipitation over the watershed, r(t) is the rainfall intensity adjusted for surface losses, t is the time since the start of rainfall, $r_o(t)$, and IA is the initial abstraction. The Green and Ampt infiltration is applied to the remaining rainfall by applying the following equation:[5]

for f(t) > XKSAT

$$F(t)=\frac{PSIF \times DTHETA}{\frac{f(t)}{XKSAT}-1} \tag{2.29}$$

for f(t) <= XKSAT

$$f(t)=r(t) \tag{2.30}$$

where F(t) is the cumulative infiltration, $f(t) = \Delta F(t)/\Delta t$ is the infiltration rate, and the parameters of the Green and Ampt method are PSIF, the wetting front suction, DTHETA, the volumetric moisture deficit and XKSAT, the hydraulic conductivity at natural saturation. The application of this equation is complicated by the fact that it is only applicable to a uniform rainfall rate. The difficulty is overcome by calculating a time to ponding. Time to ponding (the time at which the ground surface is saturated) is calculated by applying equation 2.30 over the computation interval Δt:[5]

for r_j >= XKSAT

$$\Delta F = F_j - F_{j-1} = \frac{PSIF \times DTHETA}{\frac{r_j}{XKSAT} - 1} - \left(\sum_{i=1}^{j-1} r_i vt\right) \tag{2.31}$$

where its recognized that at ponding the infiltration and rainfall rates are equal $(i(t) = r(t))$, r_j is the average rainfall rate during period j, F_j and F_{j-1} are the cumulative infiltration rates at the end of periods j and j-1, ΔF is the incremental infiltration over period j. Ponding occurs if the following condition is satisfied:[5]

$$\Delta F < r_j \Delta t \tag{2.32}$$

otherwise the rainfall over the period will be completely infiltrated. Once ponding has occurred, the infiltration and rainfall rates are independent and Equation 2.29 can be easily integrated to calculate the infiltration over the computation interval. The ponded surface condition might not be maintained

during the entire storm. This occurs when the rainfall rate falls below the post-ponding infiltration rate. In this case, a new ponding time is calculated and the infiltration calculation is applied as previously described.[5]

Channel Routing. In this analysis, the Muskingum-Cunge channel routing routine was chosen. This method most closely approximates the diffusive wave channel routing routine found in CASC2D. The Muskingum-Cunge routing technique can be used to route lateral inflow from either kinematic wave overland flow plane or lateral inflow from collector channels and/or upstream hydrograph through a main channel.[5] The channel routing technique is a non-linear coefficient method that accounts for hydrograph diffusion based on physical channel properties and the inflowing hydrograph. The advantages of this method over other hydrologic techniques are: (1) the parameters of the model are physically based; (2) the method has been shown to compare well against the full unsteady flow equations over a wide range of flow situations; and (3) the solution is independent of the user specified computation interval. The major limitations of the Muskingum-Cunge application in HEC-1 are that: (1) it can not account for backwater effects; and (2) the method begins to diverge from the full unsteady flow solution when very rapidly rising hydrographs are routed through very flat slopes (i.e., channel slopes less than 1 ft./mile).[5] The basic formulation of the

equations is derived from the continuity equation:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=q_L \tag{2.33}$$

and the diffusion form of the momentum equation

$$S_f=S_o-\frac{\partial h}{\partial X} \tag{2.34}$$

By combining Equations 2.33 and 2.34 and linearizing, the following convective diffusion equation is formulated:[5]

$$\frac{\partial Q}{\partial t}+c\frac{\partial Q}{\partial X}=\mu_h\frac{\partial^2 Q}{\partial x^2}+cq_L \tag{2.35}$$

where

- Q = Discharge in cfs
- A = Flow area in ft^2
- t = Time in seconds
- x = Distance along the channel in feet
- h = Depth of flow in feet
- μ_h = hydraulic diffusivity
- q_L = Lateral inflow per unit of channel length
- S_f = Friction slope
- S_o = Bed slope
- c = The wave celerity in the x-direction as defined below.

$$c=\frac{\Delta Q}{\Delta A} \tag{2.36a}$$

The grid celerity (c_g) is expressed as follows:

$$c_g=\frac{\Delta x}{\Delta t} \tag{2.36b}$$

The hydraulic diffusivity (μ_h) is expressed as follows:

where B is the top width of the water surface.

$$\mu_h = \frac{Q}{2BS_o} \tag{2.37a}$$

The numerical diffusivity (μ_n) is expressed as follows:

$$\mu_n = c\Delta x\left(\frac{1}{2} - X\right) \tag{2.37b}$$

The grid diffusivity (μ_g) is expressed as follows (case where X=0 in Equation 2.37b):

$$\mu_g = \frac{c\Delta x}{2} \tag{2.37c}$$

Following a Muskingum-type formulation, with lateral inflow, the continuity equation, Equation 2.33, is discretized on the x-t plane (Figure 2.2) to yield:[5]

$$Q_{j+1}^{n+1} = C_1 Q_j^n + C_2 Q_j^{n+1} + C_3 Q_{j+1}^n + C_4 Q_L \tag{2.38}$$

where

$$C_1 = \frac{\frac{\Delta t}{K} + 2X}{\frac{\Delta t}{K} + 2(1-X)}$$

$$C_2 = \frac{\frac{\Delta t}{K} - 2X}{\frac{\Delta t}{K} + 2(1-X)}$$

$$C_3 = \frac{2(1-X) - \frac{\Delta t}{K}}{\frac{\Delta t}{K} + 2(1-X)}$$

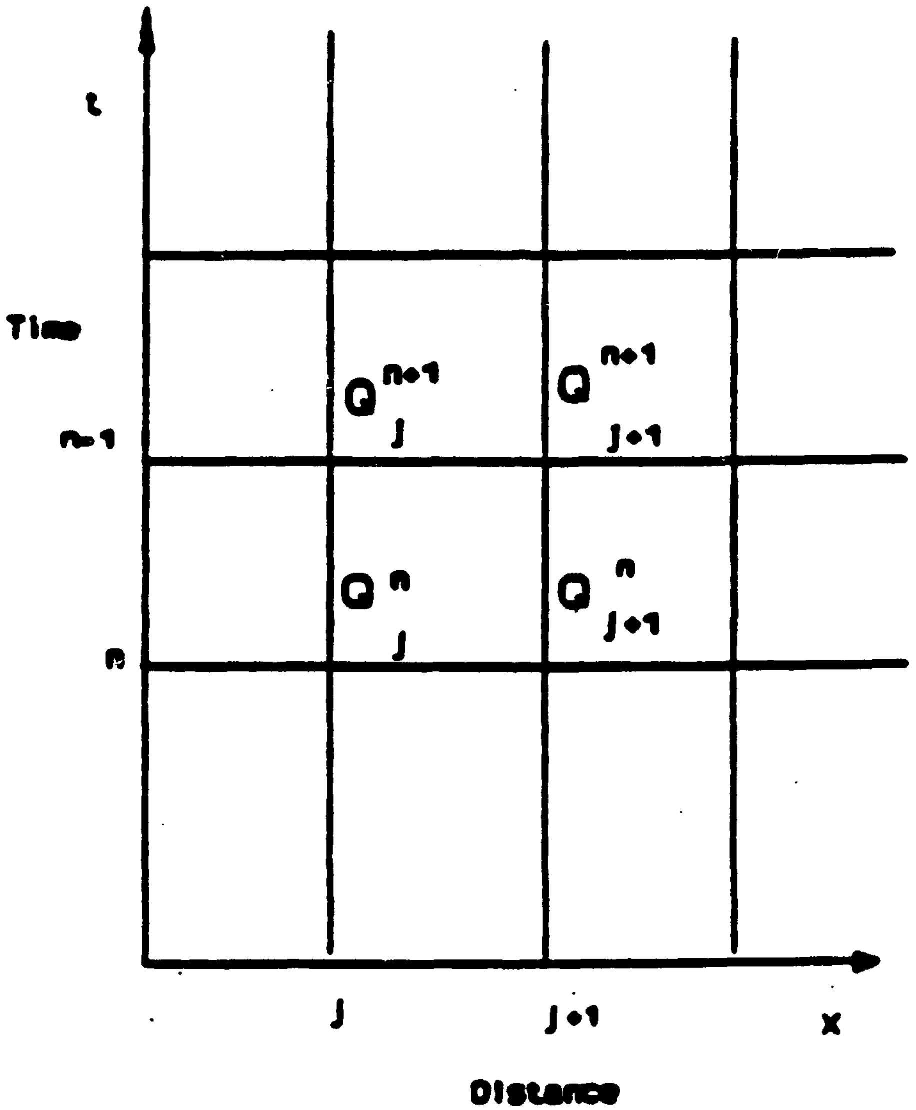

Figure 2.2 - Discretization on x-t Plane of the Variable Parameter Muskingum-Cunge Model. (HEC-1 User's Manual)

$$C_4=\frac{2\left(\frac{\Delta t}{K}\right)}{\frac{\Delta t}{K}+2(1-X)}$$

$$Q_L=q_L\Delta x$$

It is assumed that the storage in the reach is expressed as the classical Muskingum storage:

$$S=K[XI+(1-X)O] \qquad (2.39)$$

where:
S = channel storage
K = cell travel time (seconds)
X = weighting factor
I = inflow
O = outflow

In the Muskingum equation, the amount of diffusion is based on the value of X, which varies between 0.0 and 0.5. The Muskingum X parameter is not directly related to physical channel properties. The diffusion obtained with the Muskingum technique is a function of how the equation is solved and is therefore considered numerical diffusion rather than physical. In the Muskingum-Cunge formulation, the amount of diffusion is controlled by forcing the numerical diffusion to match the hydraulic diffusion (μ_h) from Equation 2.35 and 2.37a. The Muskingum-Cunge equation is therefore considered an approximation of the convective diffusion equation, Equation 2.35. As a result, the parameters K and X are expressed as follows:[5]

$$K=\frac{\Delta x}{c} \qquad (2.40)$$

$$X=\frac{1}{2}\left(1-\frac{Q}{BS_o\Delta x}\right) \tag{2.41}$$

Then the Courant (C) and cell Reynolds (D) numbers can be defined as:[5]

$$C=c\frac{\Delta t}{\Delta x} \tag{2.42}$$

and

$$D=\frac{Q}{BS_o c\Delta x} \tag{2.43}$$

The Courant number (C) is the ratio of the wave celerity to the grid celerity (Equations 2.36a and 2.36b). The Courant number is a fundamental concept in the numerical solution of hyperbolic partial differential equations. The cell Reynolds number (D) is the ratio of the hydraulic diffusivity to the grid diffusivity (Equations 2.37a and 2.37c).[10]

The routing coefficients for the non-linear diffusion method (Muskingum-Cunge) are then expressed as follows:[5]

$$C_1=\frac{1+C-D}{1+C+D}$$

$$C_2=\frac{-1+C+D}{1+C+D}$$

$$C_3=\frac{1-C+D}{1+C+D}$$

$$C_4=\frac{2C}{1+C+D}$$

in which the dimensionless numbers C and D are expressed in terms of physical quantities (Q, B, S_0, and c) and the grid dimensions (Δx and Δt).[5] The method is non-linear in that the flow hydraulics (Q, B, c) and therefore the routing coefficients (C_1, C_2, C_3, C_4) are re-calculated for every Δx distance step and Δt time step. An iterative four-point averaging scheme is used to solve for c, B, and Q. This process has been described in detail by Ponce (1986).[5]

Values for Δt and Δx are chosen internally by the model for accuracy and stability. First, Δt is evaluated by looking at the following three criteria and selecting the smallest value:[5]

(1) The user defined computation interval, NMIN, from the field of the IT record.

(2) The time of rise of the inflow hydrograph divided by 20 (T_r/20).

(3) The travel time of the channel reach.

Once Δt is chosen, Δx is evaluated as follows:[5]

$$\Delta x = c\Delta t \tag{2.44}$$

but Δx must also meet the following criteria to preserve consistency in the method:

$$\Delta x < \frac{1}{2}\left(c\Delta t + \frac{Q_o}{BS_o c}\right) \tag{2.45}$$

where Q_o is the reference flow and Q_B is the baseflow taken from the inflow hydrograph as:[5]

$$Q_o = Q_B + 0.50\,(Q_{peak} - Q_B) \qquad (2.46)$$

Δx is chosen as the smaller value from the two criteria. The values chosen by the program for Δx and Δt are printed in the output, along with computed peak flow. Before the hydrograph ordinate is used in subsequent operations, or printed in the hydrograph tables, it is converted back to the user-specified computation interval. The user should always check to see if the interpolation back to the user-specified computation interval has reduced peak flow significantly. If the peak flow computed from the internal computation interval is markedly greater than the hydrograph interpolated back to the user-specified computation interval, the user-specified computation interval should be reduced and the model should be executed again.[5]

CHAPTER III - APPLICATION OF HEC-1 AND CASC2D MODELS TO GOODWIN CREEK WATERSHED

Description of Watershed Data

As shown in Figure 3.1, Goodwin Creek watershed contains approximately 8.4 square miles and is located within the Long Creek watershed. There are 17 rainfall gages and 14 discharge gages located within the boundary of the watershed. For this analysis, 5 mainstem discharge gages and 1 tributary gage were used. These 6 discharge gages are spread uniformly over the watershed. Since the main goal was to evaluate how the models performed in an ungaged watershed scenario, these gages provided enough information to draw conclusions and to make recommendations. Fifty seven channel cross sections on the main stem and the tributaries provide the necessary data for constructing the channel geometric database. Figure 3.2 shows the bottom elevation profile for the main stem channel. The period of record for the rainfall and flow data is approximately 7 years, 1981 to 1988. As a part of the U.S. Army Corps of Engineers's Demonstration Erosion Control Project, a Geographic Information System (GIS) database has been created for Goodwin Creek watershed. The GIS contains such data as landuse grids, soil type grids, elevation grids, SCS curve number grids, slope grids, USGS digital line graphics, and aerial photography. The grid cell resolution for all the grids used in this study were 416 feet by 416 feet.

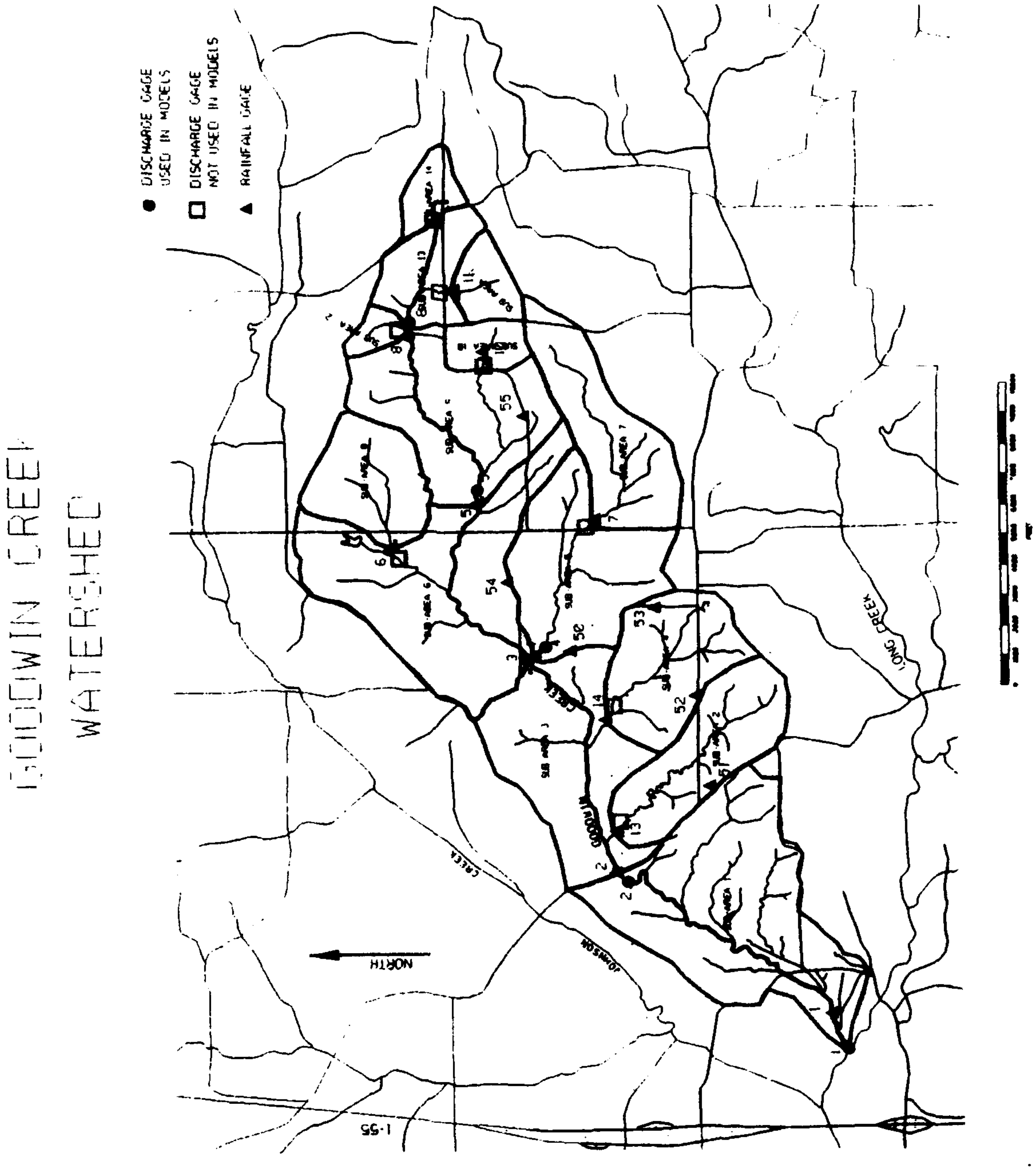

Figure 3.1 - Goodwin Creek Watershed Map

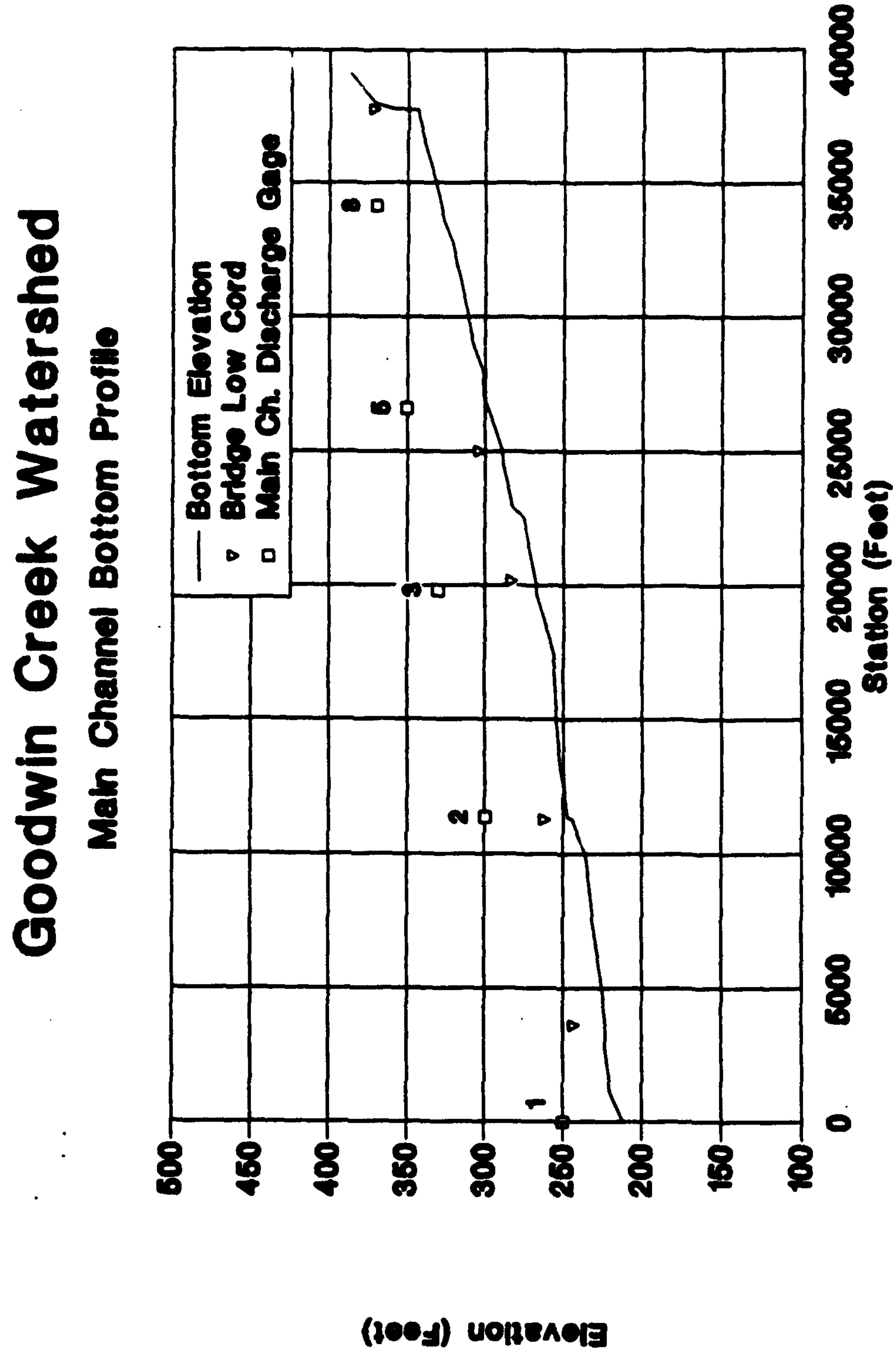

Figure 3.2 - Main Channel Bottom Profile/Goodwin Creek

Based upon personal conversations with Dr. Bahram Saghafian (Construction Engineering Research Laboratory, U.S. Army Corps of Engineers) and Dr. Fred Ogden (University of Iowa), this resolution was adequate for the Goodwin Creek Watershed.

The landuse for this watershed varies from forest, to crop land, to pasture, and to small ponds. Over the past 10 to 20 years, this area has experienced streambank instability and sedimentation problems due to changes in landuse. There are three primary soil types in the watershed; namely, Loam, Sandy Loam, and Silt Loam, with Silt Loam being the predominant soil type. The maximum elevation is 412.9 feet NGVD and the minimum elevation is 236.8 feet NGVD.

In setting up the models, the grid cell data (i.e., landuse, soil type, elevation) had to be extracted from the GIS and manipulated into the proper format for CASC2D. The lumped models used the GIS to compute average values (i.e., roughness coefficients, soil types) for each subarea. The channel cross sections were averaged for each routing reach by plotting the cross sections for each reach and estimating the average cross section for each reach.

For the past 12 years, the ARS has been extensively gaging the Goodwin Creek Watershed. The data currently being gathered is rainfall, discharge, suspended sediment, and bed load. The ARS is also generating landuse grids, from various time periods, for this watershed. The field sampling and measurement stations are located at grade control structures

built in the late 1970's. This effort was a joint project conducted by the ARS and the Army Corps of Engineers. All fourteen structures can be seen on Figure 3.1 labeled as either discharge gage used in models or discharge gage not used in models.

Application of Models and Methods

There were two parts to the Goodwin Creek Analysis. In the first part, 5 rainfall events were simulated using 17 rainfall gages and 6 discharge gages. Two HEC-1 models, SCS Unit Hydrograph and Snyder Unit Hydrograph, and CASC2D were used to simulate rainfall runoff for the purpose of comparing them to observed flow records. In this analysis, all models used the Green and Ampt infiltration routine. The HEC-1 models used the Muskingum-Cunge channel routing routine while CASC2D used a one-dimensional diffusive wave routine. Table 3.1 shows the final sub-basin parameters and Table 3.2 shows the final channel routing reach parameters. From the output, the peak flow, time to peak, volume of runoff, and hydrograph variance parameters were summarized for all three models.

In part two of this analysis, two hypothetical storm events were simulated using one rainfall gage (no. 54) data considered to be representative of the average observed storm conditions. This analysis was performed using only one lumped model (Snyder) and the distributive model (CASC2D). The reason for only comparing one lumped model (Snyder) instead of two

Table 3.1 - Goodwin Creek Watershed Sub-Basin Parameters

Sub-Basin I.D.	Area (Mi^2)	L (Mi)	Lca (Mi)	Lag Time (Hours)	Average Basin Slope (%)
1	1.44	2.62	1.22	1.28	3.20
2	.80	1.85	1.10	1.11	1.82
3	.90	1.57	.83	.97	3.22
4	.60	1.13	.61	.80	2.07
5	.78	1.33	.72	.89	3.70
6	1.29	1.50	.86	.97	3.23
7	.63	1.50	.74	.93	3.63
8	.46	.76	.48	.67	3.60
9	.86	1.39	.80	.93	3.69
10	.15	.28	.17	.36	3.73
11	.17	.31	.21	.40	2.24
12	.07	.27	.18	.36	4.71
13	.31	.68	.42	.62	4.72
14	.14	.21	.15	.32	1.30

Table 3.2 - Goodwin Creek Channel Routing Reach Parameters

Reach I.D.	Length (Mi)	Bed Slope (Ft/Mi)	Manning's "n" LOB	Manning's "n" Main Channel	Manning's "n" ROB
18 to 17	.39	21.65	.080	.040	.080
17 to 15	.39	20.38	.080	.040	.080
16 to 15	.47	21.12	.080	.040	.080
15 to 14	.72	27.09	.080	.040	.080
13 to 12	1.04	41.76	.100	.040	.100
12 to 10	.66	23.39	.070	.038	.070
11 to 10	.54	28.62	.070	.038	.070
10 to 7	.69	16.63	.070	.038	.070
9 to 8	.53	25.45	.080	.035	.080
8 to 7	.53	25.45	.080	.035	.080
7 to 5	.77	20.12	.070	.038	.070
6 to 5	.64	39.60	.070	.038	.070
5 to 3	.78	10.19	.070	.038	.070
4 to 3	1.20	35.43	.070	.038	.070
3 to 2	1.09	15.47	.070	.037	.070
2 to 1	1.09	8.18	.070	.037	.070

lumped models (Snyder and SCS), as in the Part I of this study, is that there are only minor differences in the methodologies (i.e., peak flow equations). Based upon the results from Part I of this study, there were only minor differences noted between the two lumped models therefore little would have been gained by running both models for Part II. The reason for this simulation scenario was to compare the models assuming a temporally varied rainfall event uniformly distributed spatially over the entire watershed.

Modeling Approach used for Comparison Study

In part one of this study, each of the selected hydrologic models has been applied to five observed storm events, using 17 rainfall gages, with the predicted discharge hydrographs compared to observed hydrographs at six stream gage locations. Each HEC-1 model was calibrated (optimizing initial loss and soil moisture content) using data at Gage No. 1 (Mouth of Goodwin Creek). Storms 1 and 3 were also calibrated at Gages 5 and 8. This was done to evaluate the relative accuracy of the lumped models when sufficient sub-basin gage data were available. Storms 2, 4, and 5 were only calibrated at the mouth of Goodwin Creek. This was done to assess the relative accuracy of the lumped models using limited gage information. CASC2D was only calibrated (optimizing initial soil moisture content) at the mouth for all five storm events. The reason for this was to evaluate the

response of a distributed model using limited gage information. Initial runs were made with no calibration at all, however, this proved unsuccessful due to a lack of knowledge about how the initial antecedent moisture and ground cover conditions changed from storm to storm.

The parameters considered in the calibration and simulation comparisons were peak flow, time to peak, total runoff volume, and four hydrograph variance values (i.e., standard error, objective function, average absolute error, and average percent absolute error). The results of final simulation computer runs can be seen in Tables A-2 to A-8. Plots of the computed hydrographs from the three models versus the observed hydrographs, for all five selected storm events, are shown in Appendix A.

In part two of this study, rainfall gage no. 54 was used to simulate the hypothetical uniform rainfall events over the watershed. All of the discharge gages were used to calibrate the HEC-1 lumped model, however only gage 1 was used to calibrate CASC2D. Storm Events 1 and 3 were chosen, because storm 1 is a slow rising and falling storm while storm 3 is a fast rising and falling storm. The same infiltration function, overland routing routine, and channel routing routine described in part one of this study were used in part two for both the Snyder HEC-1 and CASC2D models. The results of final computer runs can be seen in Tables B-1 to B-7. Plots of discharge hydrographs for storms 1 and 3 at Gages 1,2,3,4,5,

and 8 can be seen in Appendix B.

Hydrograph Variance Parameters

Standard Error. Standard Error is defined as the root mean squared sum of the difference between observed and computed hydrograph ordinates.

$$S_e=\left[\sum_{i=1}^{n}\frac{(QOBS_i-QCOMP_i)^2}{n}\right]^{\frac{1}{2}} \tag{3.1}$$

Objective Function. The best reconstruction, of a computed hydrograph, is considered to be that which minimizes an objective function, STDER. The objective function is the square root of the weighted square difference between the observed and computed hydrograph ordinates. Presumably, this difference will be a minimum for the optimal parameter estimates. STDER is computed as follows:[5]

$$STDER=\left[\sum_{i=1}^{n}(QOBS_i-QCOMP_i)^2\times\frac{WT_i}{n}\right]^{\frac{1}{2}} \tag{3.2}$$

where $QCOMP_i$ is the computed runoff hydrograph ordinate and $QOBS_i$ is the observed runoff hydrograph ordinate i for the time period, n is the total number of hydrograph ordinates, and WT_i is the weight for the hydrograph ordinate i computed from the following equation:[5]

$$WT_i=\frac{QOBS_i+QAVE}{2\times QAVE} \tag{3.3a}$$

where

$$QAVE=\frac{\sum_{i=1}^{n} QOBS_i}{n} \tag{3.3b}$$

QAVE is the average observed discharge.

Average Absolute Error. Average Absolute Error is defined as the average of the absolute value of the differences in flowrate between observed and computed hydrographs.

$$AAE=\frac{\sum_{i=1}^{n} |QOBS_i-QCOMP_i|}{n} \tag{3.4}$$

Average Percent Absolute Error. Average Percent Absolute Error is defined as the average of absolute value of percent difference between observed and computed hydrograph ordinates.

$$APAE=\frac{\sum_{i=1}^{n} \left|\frac{QOBS_i-QCOMP_i}{QOBS_i}\times 100\right|}{n} \tag{3.5}$$

CHAPTER IV - DISCUSSION OF SIMULATION RESULTS

Part I - Observed Rainfall-Runoff Events

Each of the three selected hydrologic models were applied to five observed storm events. Simulated streamflow hydrographs were compared to observed hydrographs at five locations on the main stem channel and one major tributary. A total of 17 rainfall gages with observed data were used to calculate the sub-basin or overland flow runoff in the watershed. Plots of the simulated streamflows versus the observed data are shown in Appendix A, Figures A-1 to A-30.

Streamflow and rainfall gage data for Goodwin Creek Watershed were available from 1981 to 1988. From an inspection of the observed streamflow data, it was noted that there was no observed events which produced a peak flow greater than the estimated 2 year flood of 3500 cfs. Therefore, the five selected observed storm events used for simulation purposes in this study are all less than the 2 year frequency runoff event. Total rainfall in inches for the 5 selected storms are shown in Table A-1 for all 17 rainfall gages.

Streamflow hydrograph parameters considered for calibration and comparison purposes included total runoff in inches (Table A-2), peak flow in cfs (Table A-3), time to peak in minutes (Table A-4), the objective function in cfs (Table A-5), the standard error in cfs (Table A-6), the average absolute error in cfs (Table A-7), and the average absolute error in percent (Table A-8). A separate discussion of the

simulated results for each of the selected storms is included below. For illustration purposes, rainfall gage 54 located near the middle of the watershed was selected for plots of the storm rainfall hyetograph. This gage was considered to closely represent an average of the 17 gages within the watershed.

Storm Event 1. The storm of Oc[illegible]7, 1981 began at 9:19 pm and had a total duration of 3.52 hours. Very little rainfall preceeded this event. The actual rainfall hyetograph for rain gage 54 is shown in Figure A-31. Total rainfall for this event varied from 2.55 to 3.11 inches with an average value of 2.85 inches (Table A-1). Total runoff varied from 0.08 inches at the upper streamflow gage to 0.70 inches at the downstream gaging location (Table A-2). Therefore, infiltration and other losses amounted to about 97% at the upper gage to 75% at the lower gage.

A comparison of the hydrograph plots (Figures A-1 to A-6) and the hydrograph parameters (Tables A-2 to A-8) show that the three models had varying degrees of simulation success. The distributed CASC2D model simulated the overall shape and rate of rise consistently better than the two HEC-1 lumped models. Also, the total volume of runoff appears to be more accurate in the CASC2D model than the HEC-1 models. However, the time to peak and peak flow values for the upper four gages seemed to be closer to the observed with the HEC-1 models than the CASC2D model. The opposite was true for the lower two

gages. This same observation is reflected in the standard and absolute error tables (i.e., that CASC2D was better on lower part of watershed and HEC-1 models were better on the upper part of the watershed). These simulation results can be attributed mainly to the fact that the lumped HEC-1 models were calibrated for the upper two gages (5 and 8) as well as the lower gage (1) while CASC2D was only calibrated using the lower gage (1).

Based upon the above analysis of the simulation results for this storm, the following observations are noted:

(1) A distributed model, such as CASC2D, containing more accurate spatial data representation of the watershed variability in soils and landuse will simulate more closely the true shape, rate of rise, and volume of the streamflow runoff hydrograph than the lumped methods of HEC-1.

(2) Lumped unit hydrograph models such as HEC-1 can reproduce observed hydrographs reasonably well, especially when sufficient sub-basin gage data is available for calibration of the unit graph and loss rate parameters.

Storm Event 2. The storm of February 9, 1982 began at 7:00 pm and had a total duration of 6.0 hours. There was a significant amount of rainfall preceeding this event. The storm hyetograph for rain gage 54 is shown in Figure A-32. Total rainfall varied from 1.24 to 1.48 inches with an average of 1.35 inches (Table A-1). Total runoff varied from 0.08

inches at the upper streamflow gage (gage 8) to 0.98 inches at the lower streamflow gage (gage 1) location (Table A-2). Therefore, infiltration and other losses amounted to 94% at gage 8 to only 27% at gage 1.

For the simulation of this storm event, all three hydrologic models were calibrated using only the flow data at gage 1. Therefore uniform flow loss parameters were estimated and used over the entire basin. Since the lower watershed rainfall gages indicated a significant amount of antecedent rainfall, the initial loss parameters were not used in HEC-1 for this simulation.

A comparison of the hydrograph plots (Figures A-7 to A-12) again shows that CASC2D model consistently simulated the overall shape and rate of rise of the hydrographs fairly accurate except for the initial 100 minutes. However, initial baseflow in the main channel was assumed to be zero for the CASC2D runs and therefore accounts for the large difference between observed values in this initial time period. Due to the large variability from one sub-basin to another in the antecedent moisture conditions, the assumptions of a uniform infiltration rate and no initial losses caused the lumped models of HEC-1 to do a poor job of simulation (either too high or too low). Simulation results of this storm also verify the two observations noted during the simulation of the first storm.

Storm Event 3. The storm event of September 30, 1985 began at 12:00 am and had a duration of 22.2 hours. There were no significant amounts of rainfall preceeding this event and infiltration and other losses were expected to be high. The hyetograph of observed rainfall for rain gage 54 is shown in Figure A-33. Total rainfall varied from 1.91 to 2.69 inches with an average value of 2.18 inches (Table A-1). Total runoff was very small varying from 0.03 inches at the upper gage (gage 8) to 0.10 inches at gage 2 near the downstream end of the watershed (Table A-2). Therefore, infiltration and other losses amounted to approximately 99% at gage 8 to about 95% at gage 2. This rainfall event is typical of the small flashy (i.e., fast rising) storms that occur several times a year in North Mississippi.

A comparison of the hydrograph plots (Figures A-13 to A-18) and the hydrograph parameters show that all of the models were able to simulate this storm event with some degree of success. Overall, CASC2D simulated the shape and rate of rise consistently better than the two HEC-1 lumped models. Also, the total volume of runoff appears to be more accurate in the CASC2D model than the HEC-1 models. As in storm event 1, the time to peak and peak flow volumes for the upper four gages seemed to be closer to the observed with the HEC-1 models than the CASC2D model. The opposite was true for the lower two gages. This same observation is reflected in the standard and absolute error tables. This storm event was calibrated the

same as storm event 1 (ie, the lumped models were calibrated at gages 1, 5, and 8 while CASC2D was only calibrated at gage 1). Based upon the results from this statement, the observations noted in storm event 1 still hold true.

Storm Event 4. The storm of December 27, 1988 began at 8:31 pm and had a total duration of 8.6 hours. Again, there was a significant amount of rainfall preceeding this storm event. The storm hyetograph for rain gage 54 is shown in Figure A-34. Total rainfall varied from 2.12 inches to 2.52 inches with an average of 2.34 inches (Table A-1). Total runoff varied from 0.09 inches at gage 8 to 1.17 inches at gage 1 (Table A-2). Therefore, infiltration and other losses amounted to 96% at gage 8 to 50% at gage 1.

For the simulation of this storm event, all three hydrologic models were calibrated using only the flow data at gage 1. Therefore, as in storm event 2, uniform flow loss parameters were estimated and used over the entire basin. Because the lower watershed rainfall gages indicated a significant amount of antecedent rainfall, the initial loss parameters were not used in HEC-1 for this simulation.

A comparison of the hydrograph plots (Figures A-19 to A-24) and the hydrograph parameters (Tables A-2 to A-8) shows that CASC2D performed better overall than did the HEC-1 models. Due to the large variability from one sub-basin to another in the antecedent moisture conditions, the assumption

of uniform infiltration rate and no infiltration losses caused the lumped models of HEC-1 to do a poor job of simulating this event. The same conclusions can be drawn from this storm event as can be drawn from the previous storm events.

Storm Event 5. The storm event of December 2, 1983 began at 12:00 am and had a duration of 31.1 hours. There was significant rainfall preceeding this event, therefore infiltration rates can be expected to be low. The hyetograph of observed rainfall for rain gage 54 is shown in Figure A-35. Total rainfall varied from 5.64 inches to 6.00 inches with an average of 5.79 inches (Table A-1). Total runoff varied from 0.37 inches at gage 8 to 4.19 inches at gage 1 (Table A-2). Therefore, infiltration and other losses amounted to 94% at gage 8 to only 28% at gage 1. Like storm events 2 and 4, all three hydrologic models were calibrated using only the flow data at gage 1. Therefore, uniform loss parameters were estimated over the entire watershed.

A comparison of the hydrograph plots (Figures A-25 to A-30) shows that CASC2D consistently simulated the overall shape and rate of rise better than the lumped models. From the hydrograph parameters, CASC2D performed better than the lumped models in simulating this event except in computing the time to peak. The lumped models were consistently better at estimating the time to peak than was the CASC2D model.

It should be stated that all three hydrologic models are single event models and therefore should not be expected to accurately simulate multiple event storms. With this in mind, all three models did a reasonably good job of estimating the runoff for this event. Finally, based on the results from this event, the observations made from storm event 1 still hold true (i.e., more spatial and sub-basin gage data results in a better simulation regardless as to whether the HEC-1 lumped models or the CASC2D distributed model is used).

Part II - Hypothetical Rainfall-Runoff Events

One HEC-1 lumped model (Snyder) and the distributed model (CASC2D) were applied to two storm events (1 and 3). For this analysis, the lumped model was calibrated using observed flow data at all six gages for both storm events. However, CASC2D was only calibrated using flow data at gage 1. Also, only one rainfall gage (gage 54) was used to calculate overland flow for the watershed. This was done to evaluate how accurate the models would simulate a storm event using an spatially uniform rainfall assumption over the entire watershed. Plots of the simulated streamflows versus the observed data can be seen in Appendix B, Figures B-1 to B-12.

Streamflow hydrograph parameters considered for calibration and comparison purposes included total runoff in inches (Table B-1), peak flow in cfs (Table B-2), time to peak in minutes (Table B-3), the objective function (Table B-4),

the standard error in cfs (Table B-5), the average absolute error in cfs (Table B-6), and the average absolute error in percent (Table B-7). A separate discussion of the simulated results for both storm events is included below.

Storm Event 1. This storm event is described in detail in Part I of the discussion of results. The total rainfall for this event was 2.84 inches (Table A-1). The total runoff varied from 0.08 at gage 8 to 0.70 at gages 1 and 2 (Table B-1). Therefore, infiltration and other losses amounted to about 97% at gage 8 to 75% at gages 1 and 2.

A comparison of the hydrograph plots (Figures B-1 to B-6) and the hydrograph parameters (Tables B-1 to B-7) show that the lumped model did significantly better than did the CASC2D model. Calibrating the lumped model sub-basin unit hydrograph parameters using the observed flows at all six stream gages seemed to negate the assumption of spatially uniform rainfall being used over the watershed. However, since CASC2D was only calibrated using observed data at gage 1, the spatially uniform rainfall assumption did seem to adversely affect the results.

Based upon the results of this simulation, the following observations can be made:

(1) The lumped model can be made to simulate relatively well with limited rainfall data as long as there is sufficient sub-basin stream flow data with which to calibrate and;

(2) For cases of limited rainfall data, CASC2D may also require more sub-basin flow data for calibration purposes. However, when there is detailed spatial rainfall data available, much less streamflow data is required compared to the lumped models. In the event that both sets of these data are absent, the simulation accuracy of CASC2D also may be questionable.

Storm Event 3. This storm is described in detail in Part I of the discussion of results. The total rainfall for this event was 2.14 inches (Table A-1). The total runoff varied from 0.03 inches at gage 8 to 0.10 inches at gage 2 (Table B-1). Therefore, infiltration and other losses amounted to about 99% at gage 8 to 95% at gage 2.

A comparison of the hydrograph plots (Figures B-7 to B-12) along with the hydrograph parameters (Tables B-1 to B-7) shows that the lumped model performed significantly better than did the CASC2D model. Again, using only the downstream gage for calibration and assuming average rainfall spread uniformly over the entire watershed, CASC2D was not able to accurately simulate this observed event. The lumped model faired much better because the calibration of parameters was based on flow data at all six gages. The results from this storm event seem to confirm the previous observations made in storm event 1.

CHAPTER V - SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

In setting up the models in this comparison study, the options in the HEC-1 model that most closely represented the components used in the CASC2D model were selected. However, the manner or solution techniques in which the equations or functions are applied in HEC-1 and CASC2D are slightly different. For example, in the Green-Ampt infiltration function component, the HEC-1 version allows for an initial loss parameter to be input for each sub-basin area. This is not available in the CASC2D version, but could be indirectly simulated by defining a depression storage value for each grid cell. Another example is the distribution of rainfall over the watershed. The CASC2D model uses an interpolation scheme based upon the inverse distance squared from the cell to the rain gages while the HEC-1 model uses a weighting factor for each rain gage based upon applying a Theissen-Polygon method to the sub-basin area. Also, the representation of cross sections for the channel routing component is different between the models. HEC-1 models the average cross section for a reach with a 8 point station-elevation scheme which includes both overbanks and the main channel and allows a different roughness value for each of the three sections of the total cross section. In the CASC2D model, the channel cross section is assumed to be rectangular and it lies in the middle of a square channel element. Any given channel path, identified by a series of

elements through which it passes, must have a constant width, depth, and roughness. For each channel element, there can be channel flow restricted to the channel width and an overland (i.e., overbank or floodplain) flow when overflow from the channel occurs.

Because of the inherent differences in the solution techniques used by the two models for solving the equations for the infiltration and channel routing components, slight differences in simulation results are to be expected. However, the totally different methodologies (i.e., lumped vs. distributed) used for solving the overland flow routing component was the principal reason for making this comparison study. Major differences in the results predicted using the two selected models are thought to be primarily due to the overland flow routing components.

The channel routing solution technique is thought to be the greatest limitation of the CASC2D model for two reasons. First, as noted previously in the discussion of the simulation results, the time to peak values predicted by the model were consistently too early as compared to observed data. The use of a rectangular cross-section shape equivalent to bank full channel size causes higher values of hydraulic radius for depths less than bank full stage thus giving higher velocities and quicker travel times. Second, the overland flows and channel routing diffusive wave equations are solved using an explicit numerical solution technique causing the time step to

be restricted to ensure stability. Generally speaking, the more intense the rainfall, the steeper the watershed, and the smaller the grid size, the shorter the time step. For too long a time step, negative depth and/or friction slopes may be computed resulting in an error message to be printed and simulation to stop. Smaller time steps are also required as the depth increases in the channel to ensure stability. This becomes a severe limitation for simulating high intensity, short duration storm events. The model could not be used for a third part of this study planned to simulate a synthetic design storm of 10 year frequency and 6 hour duration equivalent to 6 inches of total rainfall using a Huff First Quartile Rainfall Distribution. During simulation, flowrates quickly reached values greater than bankfull (i.e., approximately 3500 cfs) and stability restrictions caused the model to quit even with a small time step of 5 seconds. Therefore, Part III - Simulation of Synthetic Design Storms, could not be completed for comparison purposes using the current version of the CASC2D model.

In the 1987 Long Creek report by Zitta & Hubbard, HEC-1 was used to calibrate Snyder's unit hydrograph coefficients for the Goodwin Creek Watershed. They used a total of 10 sub-basins and 13 storms in their analysis. Five of the storms that had nearly uniform rainfall over the watershed were selected for calibration purposes and the other storms were used for verification. These values of Snyder's coefficients,

C_p=0.843 and C_t=0.90, were also used in our study and appear to work reasonably well. Computed lag time values were adjusted to the selected time step (duration) of 2 minutes for simulation purposes and this value of lag time was used with the SCS unit hydrograph method in HEC-1.

Since the beginning of this study, new research and development of the CASC2D model is underway. One version of CASC2D contains a soil moisture accounting routing and is interfaced with the GRASS GIS to make it a continuous simulation model (Dr. Bahram Saghafian, personal communication). Another investigation (Dr. Fred Ogden, personal communication) is working on a version using a Holly-Priessman implicit numerical technique for the channel routing component. Coordination is on-going by WES to have these new versions tested and verified and then combined into a working comprehensive model that will handle a variety of hydrologic modeling problems.

Future development will also include the addition of upland sediment yield and overland and channel sediment transport routines. This will allow the user to estimate sediment loads from various upland landuse changes to assist in the design of sediment and erosion control structures. CASC2D has the ability to use rainfall data from a weather radar system. As better radar rainfall data becomes available, it will enhance the desirability and use of this model in the future.

Conclusions

Based upon the results of the observed and hypothetical storm events simulated for the Goodwin Creek Watershed, the following conclusions can be made:

(1) In the case where there is accurate spatial data representation of the watershed variability in soils and landuse, a distributed model will simulate more closely the true shape, rate of rise, and volume of the streamflow runoff hydrograph than the lumped unit hydrograph methods;

(2) In the case where there is sufficient sub-basin stream gage data available for calibration purposes, the lumped unit hydrograph models such as HEC-1 can reproduce the observed hydrograph reasonably well;

(3) The lumped models rely heavily on sub-basin stream gage data in order to adequately simulate the observed hydrograph, however CASC2D can simulate adequately as long as accurate spatial data is available. If accurate spatial data and sub-basin stream gage data are both lacking, then both models (i.e., lumped or distributed) may produce questionable results;

(4) Since the distributive model CASC2D consistently produced more realistic results in terms of hydrograph shape and volume of runoff, it offers more flexibility, when performing sediment studies, than the lumped unit hydrograph models. This will be especially true when evaluating the effects of specific landuse changes or agricultural best

management practices on erosion and sediment control within the watershed;

(5) In performing this study, a GIS database had already been developed. In the case where a GIS database does not exist, a decision will have to be made as to whether an intensive stream gaging operation is more cost effective than developing data in a GIS. As time goes by, more GIS information will be available for a low cost. This should help to facilitate the development of a specific watershed GIS database and thus help to reduce the amount of stream gage data needed. Once a GIS database is developed, a distributed model will be no more difficult to setup than a lumped model. In the event that a lumped model is still desired, the GIS data will help estimate the unit hydrograph and infiltration parameters with more accuracy than traditional methods.

Recommendations

The principal objective of this study was to evaluate the watershed hydrology model, CASC2D, for purposes of application to ungaged watersheds. The simulation results from this study show that the CASC2D model will produce adequate results for design purposes with a limited amount of gage data. GIS databases are currently being developed for most of the watersheds located in North Mississippi that will be part of the Demonstration Erosion Control Project. Because less sub-basin stream gage data needs to collected for use with a

distributive model than a lumped model, it is recommended that the CASC2D model be used as an aid in the design and evaluation of streambank erosion and grade control structures in the future.

It is recommended that the channel routing component of the CASC2D model be revised as soon as possible to more realistically represent the channel cross sections in order to improve the timing of the simulated runoff hydrographs. It is also recommended that the channel routing component be uncoupled or separated from the overbank routing component for modeling overbank flows. This would allow other numerical channel routing techniques to be evaluated and perhaps eliminate the stability problems caused by too long of time steps. For design purposes of the erosion control measures, the model must be able to handle high intensity, short duration storm events. It is also recommended in the near future, that the CASC2D model be enhanced by adding sediment yield and transport subroutines for both the overland flow and channel routing components. This will allow evaluation of planned watershed best management practices and erosion or sediment control structures.

For future use of the HEC-1 model with Snyder's unit hydrograph method on streams located in North Mississippi that have similar watershed characteristics of Goodwin Creek, it is recommended that the values used in this study will be good starting approximations for calibrations or simulations.

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BIBLIOGRAPHY

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APPENDIX A - Tables and Hydrographs

for Simulation of Observed Storm Events

Table A-1 - Totul Rainfall (Inches) - Part I

Rainfall Gage	Storm Event 1	2	3	4	5
1	2.66	1.48	1.96	2.43	5.81
2	2.81	1.44	1.92	2.41	5.81
4	2.91	1.41	2.00	2.44	5.77
5	3.01	1.34	2.18	2.41	5.69
6	2.66	1.44	2.05	2.50	5.81
7	2.96	1.31	2.32	2.31	5.68
8	2.90	1.29	2.57	2.34	5.85
10	3.04	1.24	2.69	2.12	5.85
11	2.97	1.24	2.58	2.14	5.67
13	2.69	1.40	1.91	2.53	6.00
14	2.79	1.37	1.98	2.32	5.79
50	3.04	1.41	2.15	2.52	5.78
51	2.81	1.37	2.00	2.15	5.91
52	2.75	1.34	1.93	2.28	5.74
53	2.55	1.27	2.11	2.29	5.85
54	2.84	1.32	2.14	2.47	5.81
55	3.11	1.24	2.49	2.17	5.64
Total	48.50	22.91	36.98	39.83	98.46
Average	2.85	1.35	2.18	2.34	5.79

Table A-2 - Total Runoff (Inches) - Part I

Discharge Gage No.	Computation Method	Storm Event 1	2	3	4	5
1	Observed	.70	.98	.09	1.17	4.19
	CASC2D	.65	.94	.09	1.10	4.68
	SCS	.53	.66	.09	.84	2.77
	Snyder	.53	.66	.09	.82	2.76
2	Observed	.70	.95	.10	.92	3.99
	CASC2D	.57	.80	.10	1.35	3.87
	SCS	.34	.42	.06	.51	1.80
	Snyder	.34	.42	.06	.51	1.80
3	Observed	.39	.46	.06	.52	1.95
	CASC2D	.31	.41	.07	.68	1.94
	SCS	.45	.73	.07	.91	3.21
	Snyder	.45	.73	.07	.90	3.20
4	Observed	.13	.16	.02	.20	.79
	CASC2D	.10	.13	.02	.22	.62
	SCS	.14	.21	.02	.26	.92
	Snyder	.14	.21	.02	.26	.92
5	Observed	.22	.22	.06	.25	1.04
	CASC2D	.20	.23	.06	.38	1.11
	SCS	.17	.24	.05	.30	1.12
	Snyder	.17	.24	.05	.29	1.12
8	Observed	.08	.08	.03	.09	.37
	CASC2D	.06	.06	.02	.11	.33
	SCS	.07	.10	.02	.11	.45
	Snyder	.07	.10	.02	.11	.45

Table A-3 - Peak Flow (CFS) - Part I

Discharge Gage No.	Computation Method	Storm Event 1	2	3	4	5
1	Observed	1405	1000	158	1219	3383
	CASC2D	1396	1046	162	1218	3086
	SCS	1532	975	158	1046	1977
	Snyder	1785	1087	185	1198	2139
2	Observed	1541	998	181	1004	3256
	CASC2D	1345	881	187	1393	2671
	SCS	1131	687	132	733	1322
	Snyder	1308	766	156	835	1414
3	Observed	1051	505	152	569	1785
	CASC2D	868	449	177	727	1406
	SCS	1182	993	164	1060	2154
	Snyder	1377	1114	177	1145	2306
4	Observed	347	188	51	250	669
	CASC2D	327	148	36	227	446
	SCS	509	354	49	355	697
	Snyder	594	395	57	403	741
5	Observed	560	277	146	313	916
	CASC2D	702	290	186	431	841
	SCS	472	349	128	359	773
	Snyder	538	391	145	399	827
8	Observed	260	110	98	124	350
	CASC2D	237	94	97	121	255
	SCS	268	175	88	158	331
	Snyder	307	194	102	175	343

Table A-4 - Time to Peak (Minutes) - Part I

Discharge Gage No.	Computation Method	Storm Event 1	2	3	4	5
1	Observed	266	296	350	328	1354
	CASC2D	232	338	380	254	1324
	SCS	232	248	272	152	1332
	Snyder	226	238	258	142	1332
2	Observed	248	248	294	306	1344
	CASC2D	210	308	298	206	1310
	SCS	200	214	198	118	1308
	Snyder	194	208	194	110	1296
3	Observed	218	224	262	292	1332
	CASC2D	196	248	244	178	1316
	SCS	234	242	264	180	1344
	Snyder	224	232	252	158	1332
4	Observed	206	234	218	264	1322
	CASC2D	164	300	174	196	1312
	SCS	206	210	200	114	1320
	Snyder	202	206	196	104	1308
5	Observed	202	224	226	268	1324
	CASC2D	172	218	200	132	1308
	SCS	224	236	224	228	1356
	Snyder	218	228	216	152	1344
8	Observed	192	208	194	224	1320
	CASC2D	162	182	166	210	1310
	SCS	194	206	182	126	1332
	Snyder	188	200	178	120	1320

Table A-5 - Objective Function (CFS) - Part I

Discharge Gage No.	Computation Method	Storm Event 1	2	3	4	5
1	Observed	---	---	---	---	---
	CASC2D	364	56	29	213	356
	SCS	324	197	71	342	531
	Snyder	498	249	86	414	534
2	Observed	---	---	---	---	---
	CASC2D	405	101	9	389	283
	SCS	401	271	57	254	569
	Snyder	460	282	67	289	566
3	Observed	---	---	---	---	---
	CASC2D	216	44	50	164	126
	SCS	153	332	23	441	373
	Snyder	188	374	29	511	412
4	Observed	---	---	---	---	---
	CASC2D	116	29	14	57	88
	SCS	86	83	6	121	55
	Snyder	151	105	9	150	71
5	Observed	---	---	---	---	---
	CASC2D	204	24	48	146	65
	SCS	93	48	13	73	94
	Snyder	70	54	10	99	82
8	Observed	---	---	---	---	---
	CASC2D	76	16	35	39	37
	SCS	15	35	9	53	31
	Snyder	27	43	18	63	35

Table A-6 - Standard Error (CFS) - Part I

Discharge Gage No.	Computation Method	Storm Event 1	2	3	4	5
1	Observed	---	---	---	---	---
	CASC2D	283	59	30	151	278
	SCS	267	200	43	256	450
	Snyder	391	250	52	299	479
2	Observed	---	---	---	---	---
	CASC2D	331	97	7	209	217
	SCS	384	291	46	208	549
	Snyder	450	310	52	233	565
3	Observed	---	---	---	---	---
	CASC2D	173	42	26	112	91
	SCS	98	213	16	249	247
	Snyder	106	232	20	283	264
4	Observed	---	---	---	---	---
	CASC2D	87	27	9	36	68
	SCS	45	58	4	60	50
	Snyder	78	71	6	72	61
5	Observed	---	---	---	---	---
	CASC2D	133	22	26	71	52
	SCS	89	40	10	38	71
	Snyder	64	42	8	50	64
8	Observed	---	---	---	---	---
	CASC2D	58	15	22	21	27
	SCS	14	25	6	26	25
	Snyder	20	30	11	30	28

Table A-7 - Average Absolute Error (CFS) - Part I

Discharge Gage No.	Computation Method	Storm Event 1	2	3	4	5
1	Observed	---	---	---	---	---
	CASC2D	172	43	15	83	170
	SCS	180	179	25	139	281
	Snyder	259	220	31	163	305
2	Observed	---	---	---	---	---
	CASC2D	203	72	5	91	119
	SCS	242	240	33	119	332
	Snyder	288	254	37	133	343
3	Observed	---	---	---	---	---
	CASC2D	106	28	9	62	54
	SCS	57	144	11	145	179
	Snyder	57	158	13	165	184
4	Observed	---	---	---	---	---
	CASC2D	52	20	5	16	38
	SCS	22	42	3	27	35
	Snyder	42	50	4	32	42
5	Observed	---	---	---	---	---
	CASC2D	77	16	14	29	34
	SCS	38	34	8	15	41
	Snyder	31	33	6	22	42
8	Observed	---	---	---	---	---
	CASC2D	36	11	12	7	15
	SCS	8	20	4	11	17
	Snyder	13	23	6	13	18

Table A-8 - Average Percent Absolute Error (%) - Part I

Discharge Gage No.	Computation Method	Storm Event 1	2	3	4	5
1	Observed	---	---	---	---	---
	CASC2D	88	24	47	109	544
	SCS	76	60	264	124	898
	Snyder	104	69	326	178	982
2	Observed	---	---	---	---	---
	CASC2D	303	26	37	145	277
	SCS	99	69	200	114	397
	Snyder	134	72	236	146	438
3	Observed	---	---	---	---	---
	CASC2D	303	22	6344	442	408
	SCS	49	59	7936	271	1780
	Snyder	68	73	11449	561	2199
4	Observed	---	---	---	---	---
	CASC2D	792	28	184	1134	1291
	SCS	68	60	78	431	3858
	Snyder	97	75	103	692	5120
5	Observed	---	---	---	---	---
	CASC2D	7318	24	1154	267	221
	SCS	52	41	74	33	286
	Snyder	71	43	74	84	348
8	Observed	---	---	---	---	---
	CASC2D	2590	36	753	821	1484
	SCS	71	63	161	442	3909
	Snyder	85	76	230	674	4864

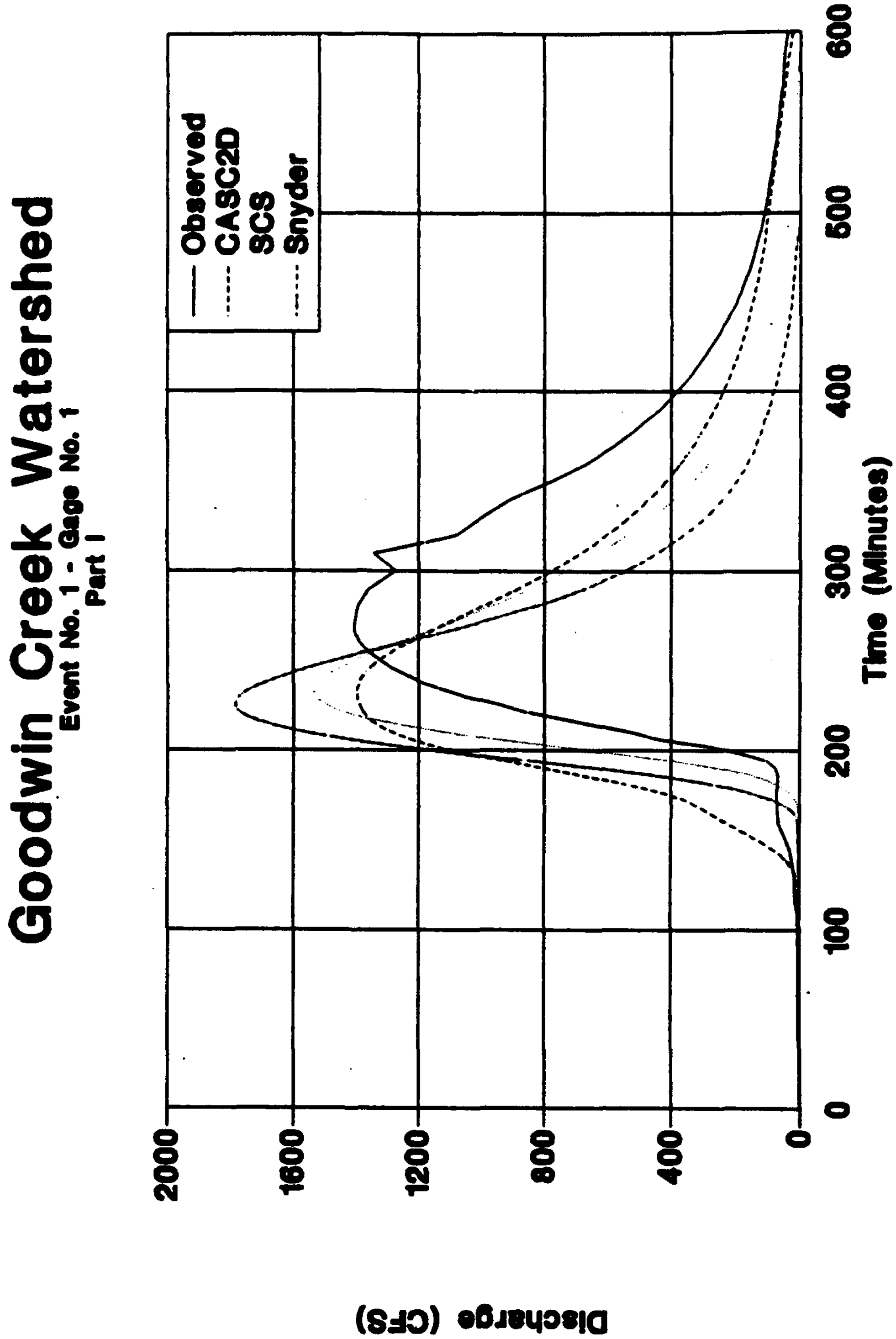

Figure A-1 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 1 at Gage 1 - Part I.

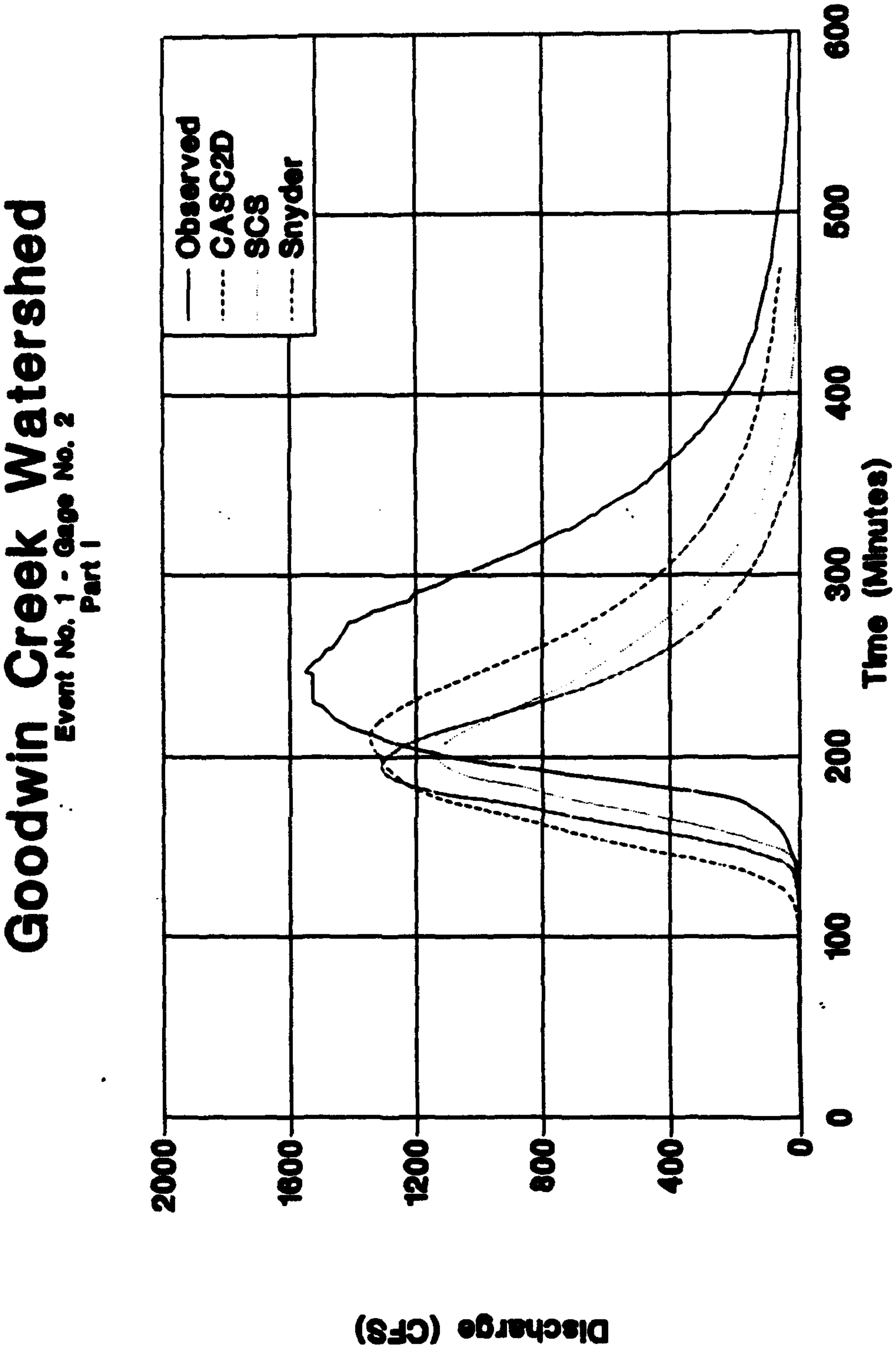

Figure A-2 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 1 at Gage 2 - Part I.

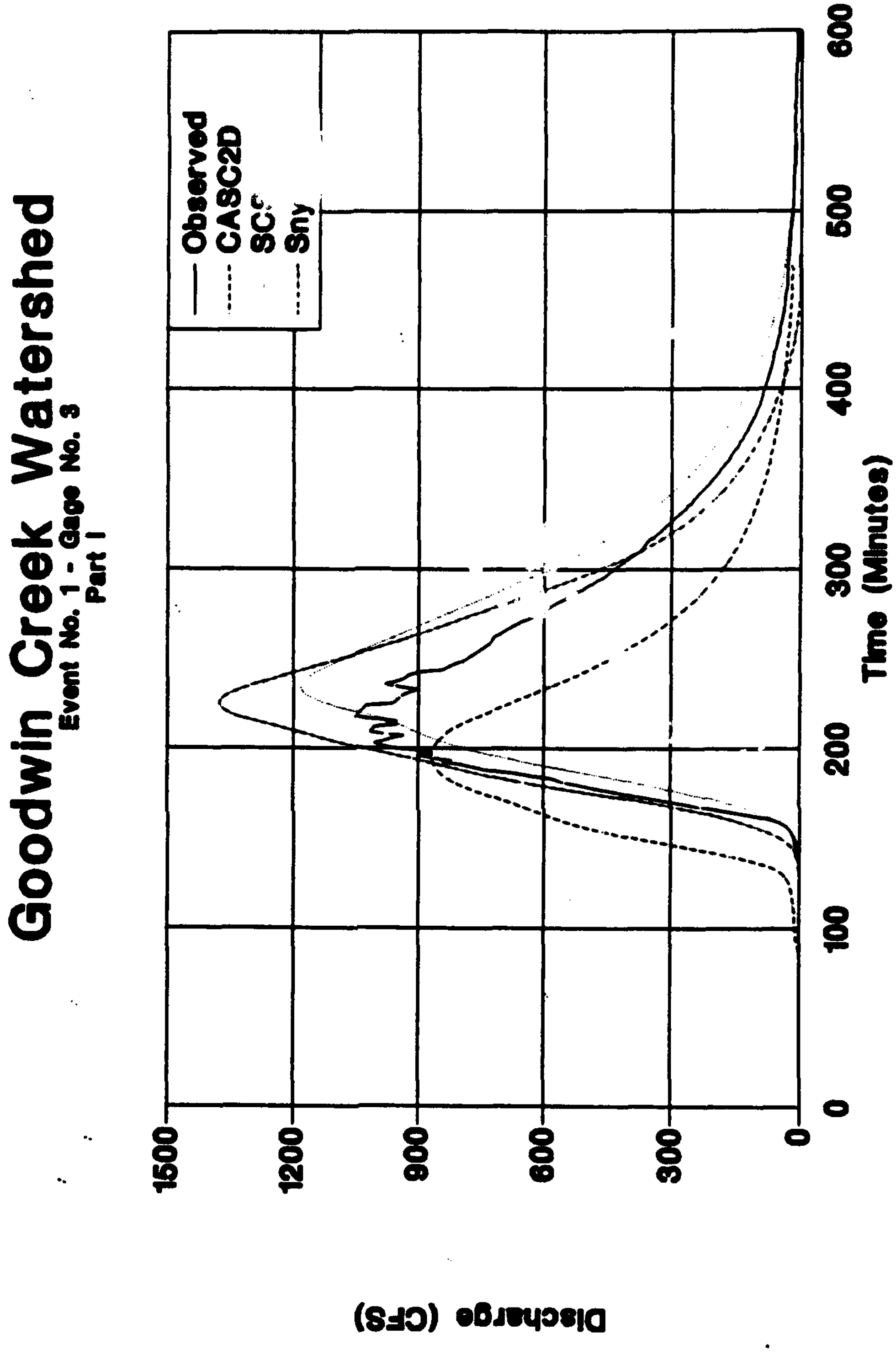

Figure A-3 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 1 at Gage 3 - Part I.

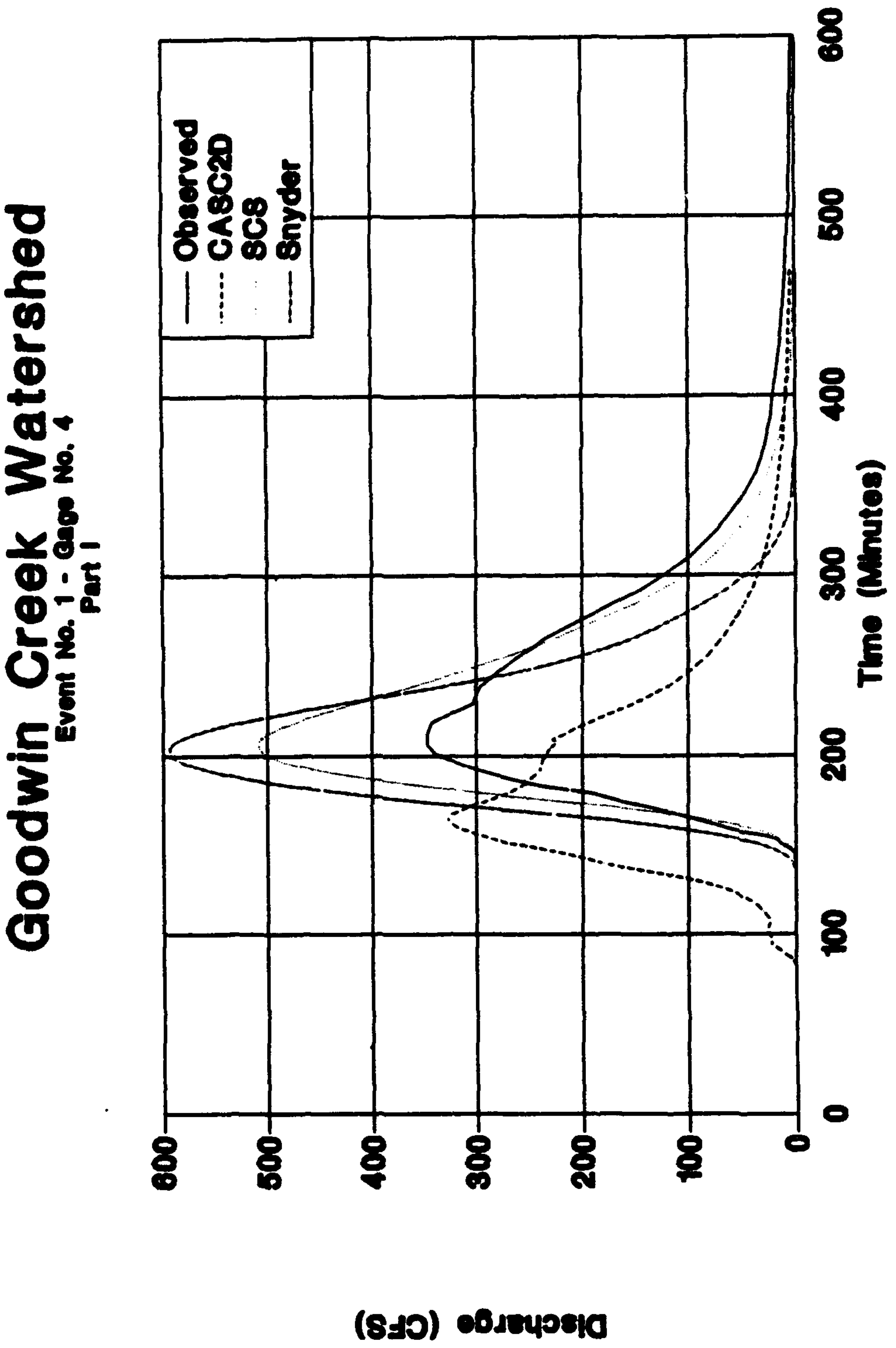

Figure A-4 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 1 at Gage 4 - Part I.

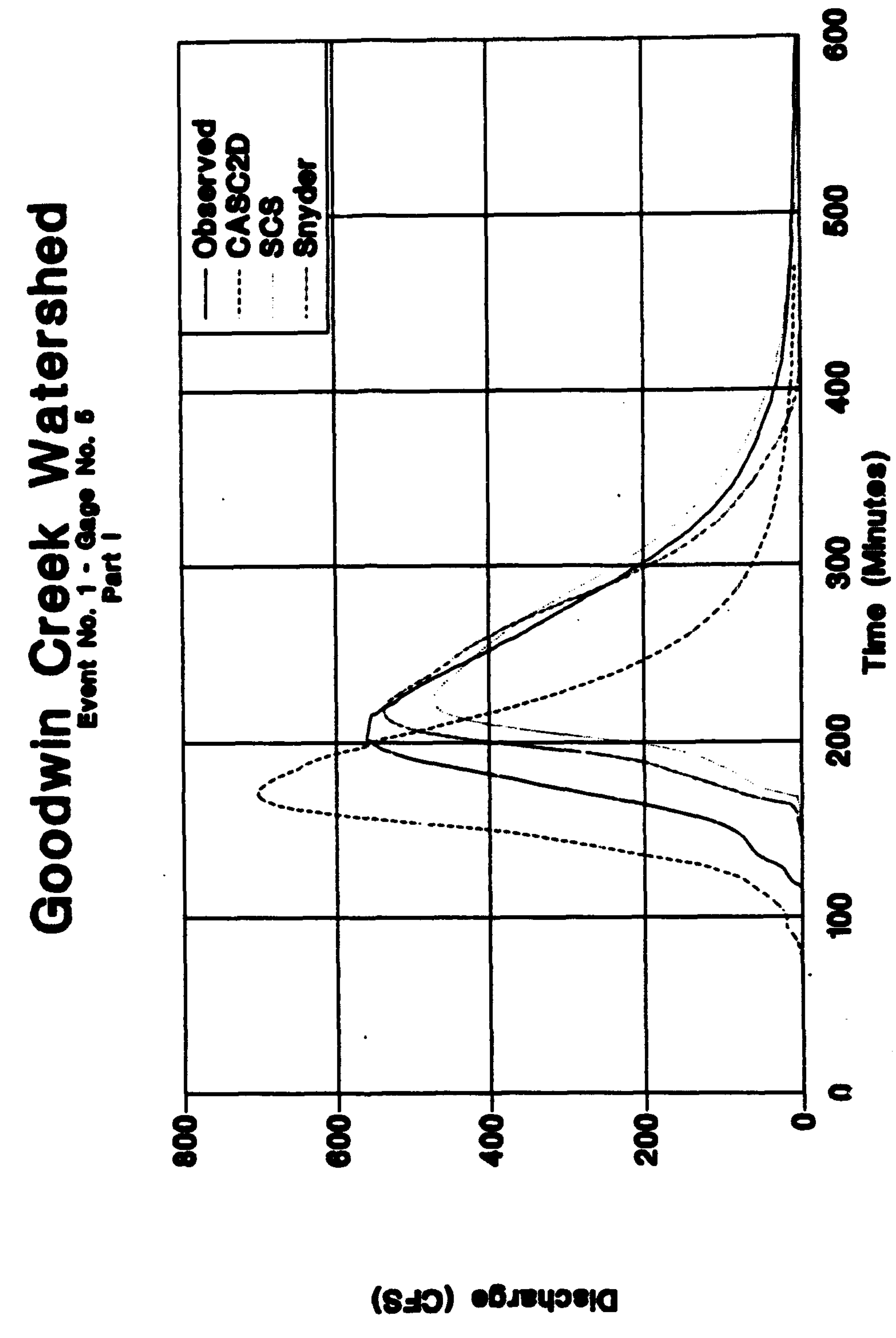

Figure A-5 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 1 at Gage 5 - Part I.

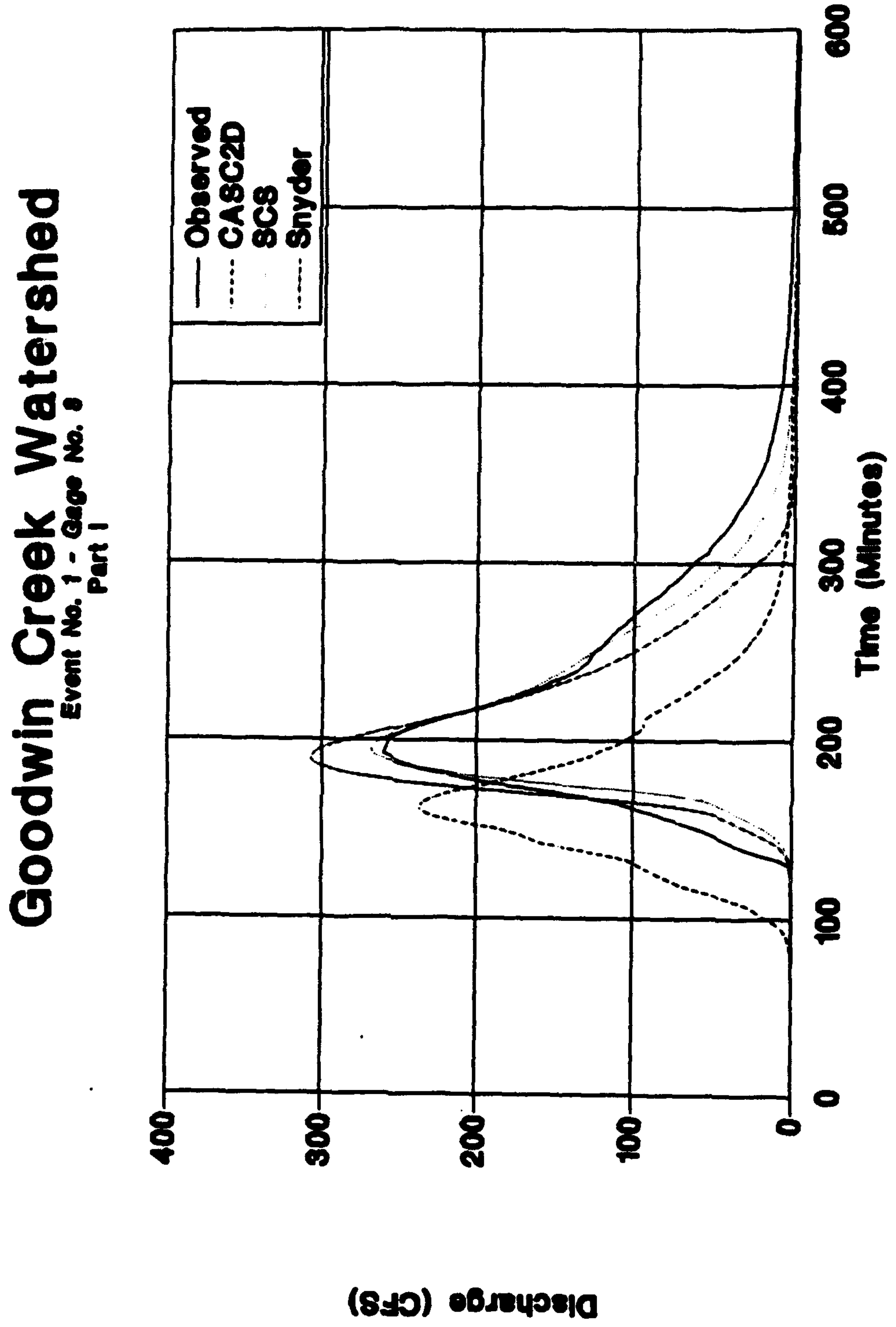

Figure A-6 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 1 at Gage 8 - Part I.

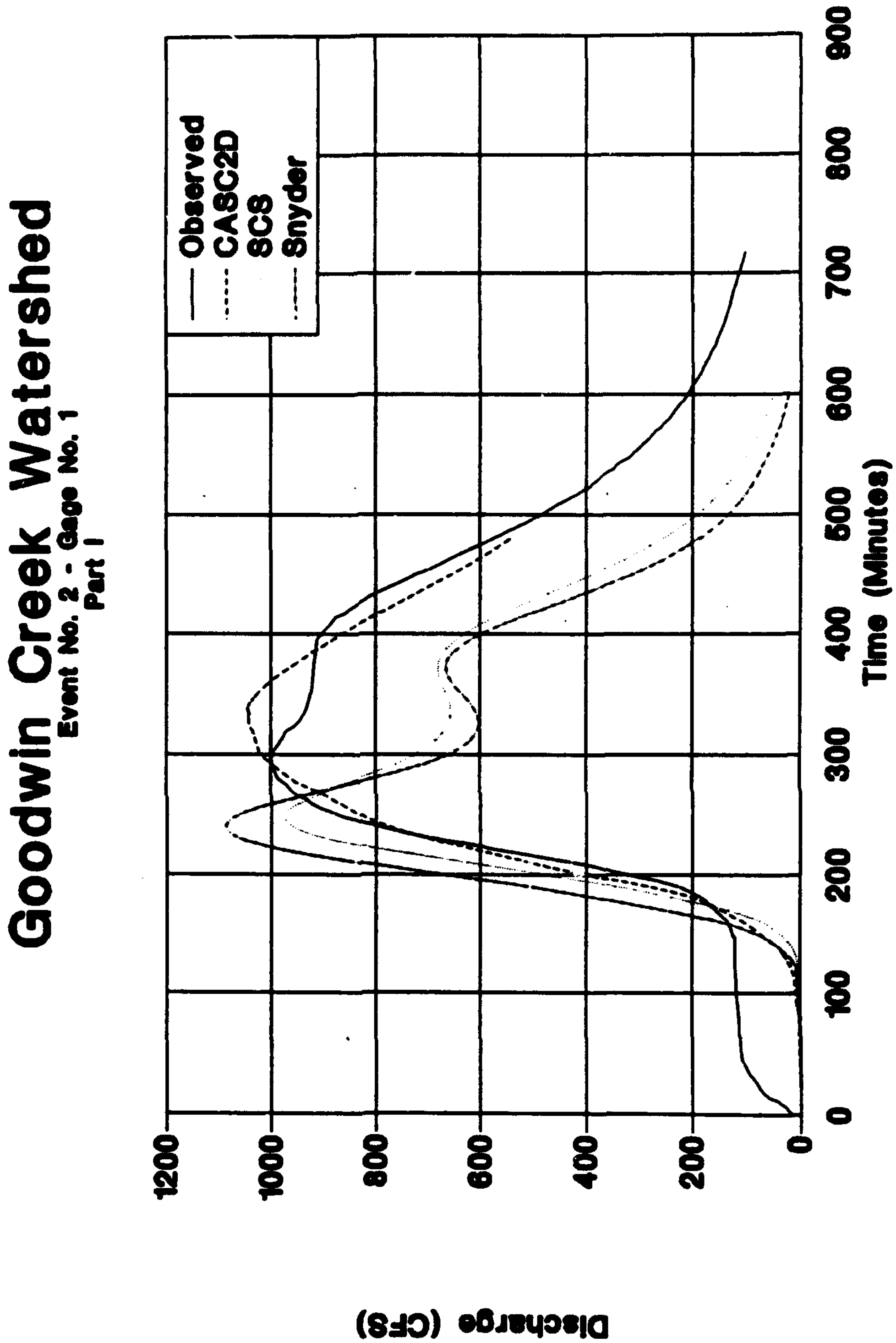

Figure A-7 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 2 at Gage 1 - Part I.

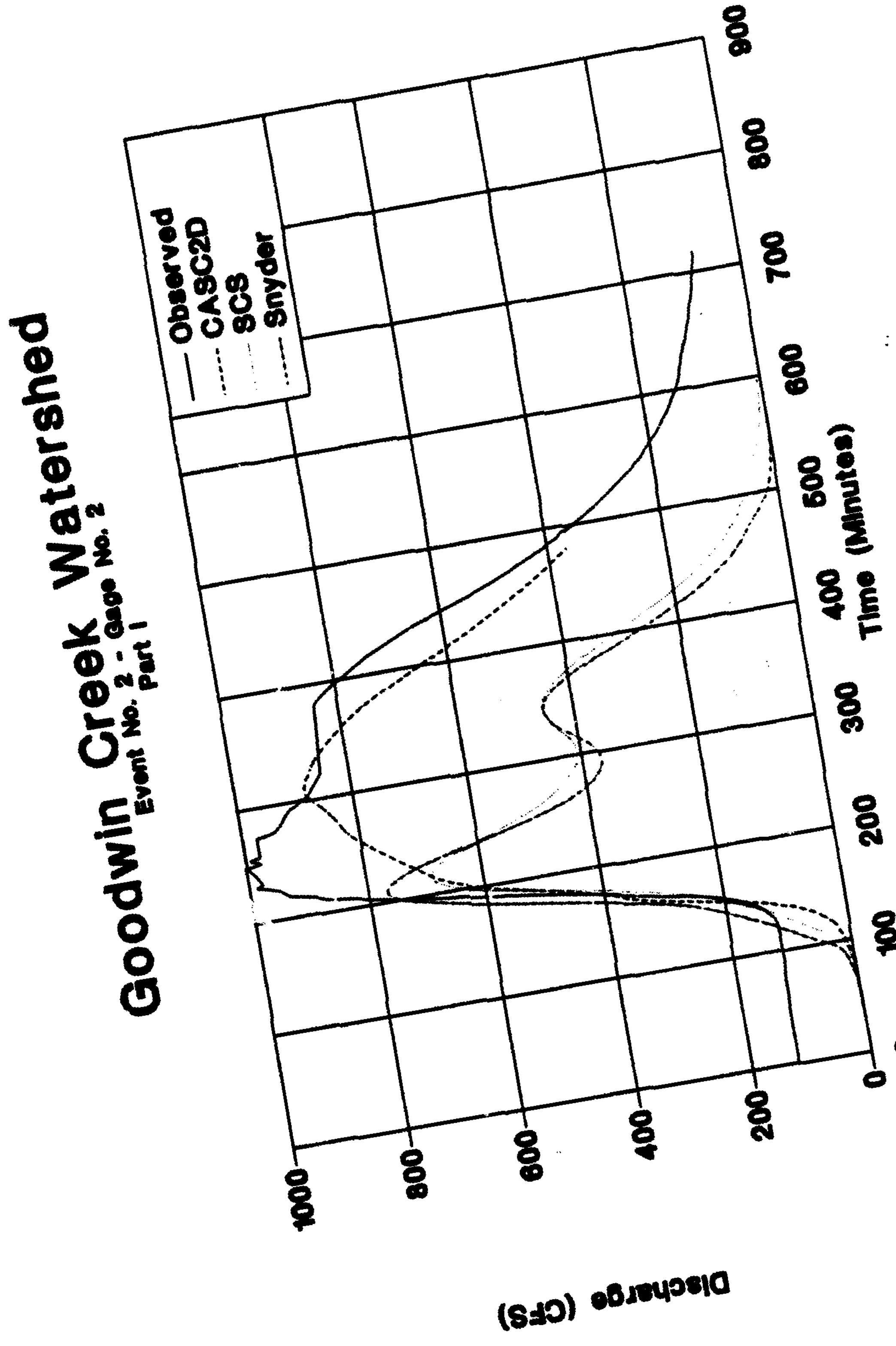

Figure A-8 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 2 at Gage 2 - Part I.

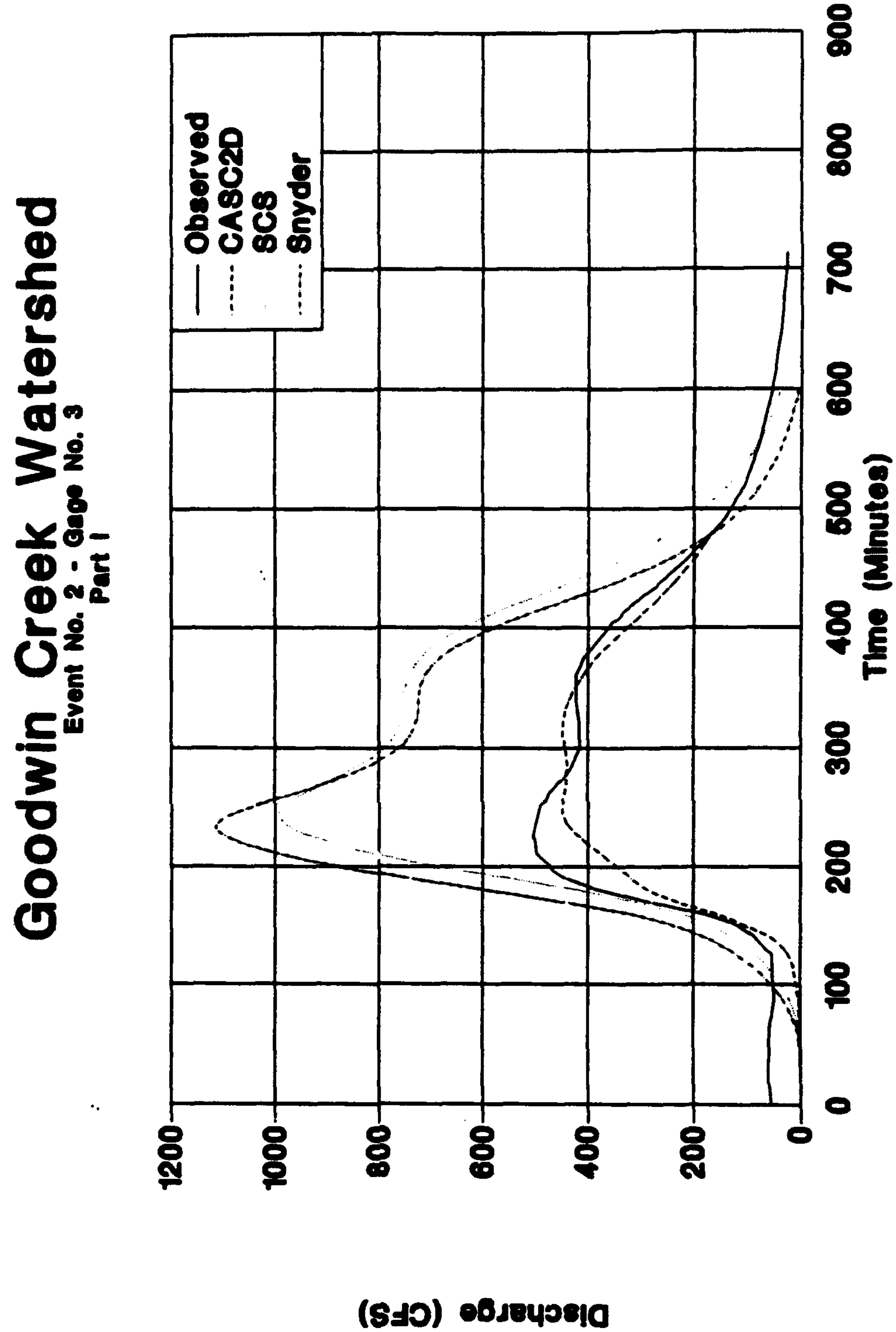

Figure A-9 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 2 at Gage 3 - Part I.

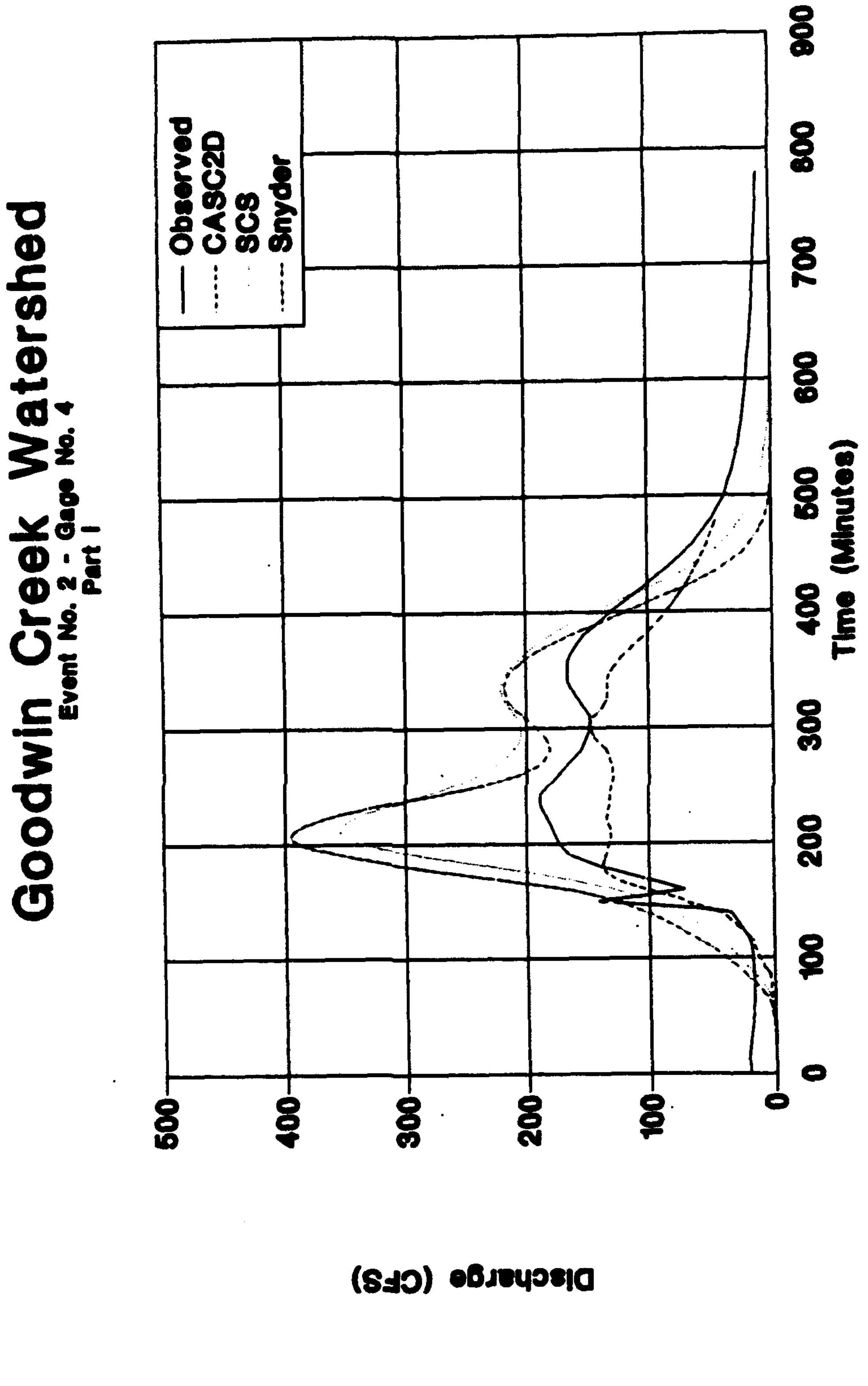

Figure A-10 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 2 at Gage 4 - Part I.

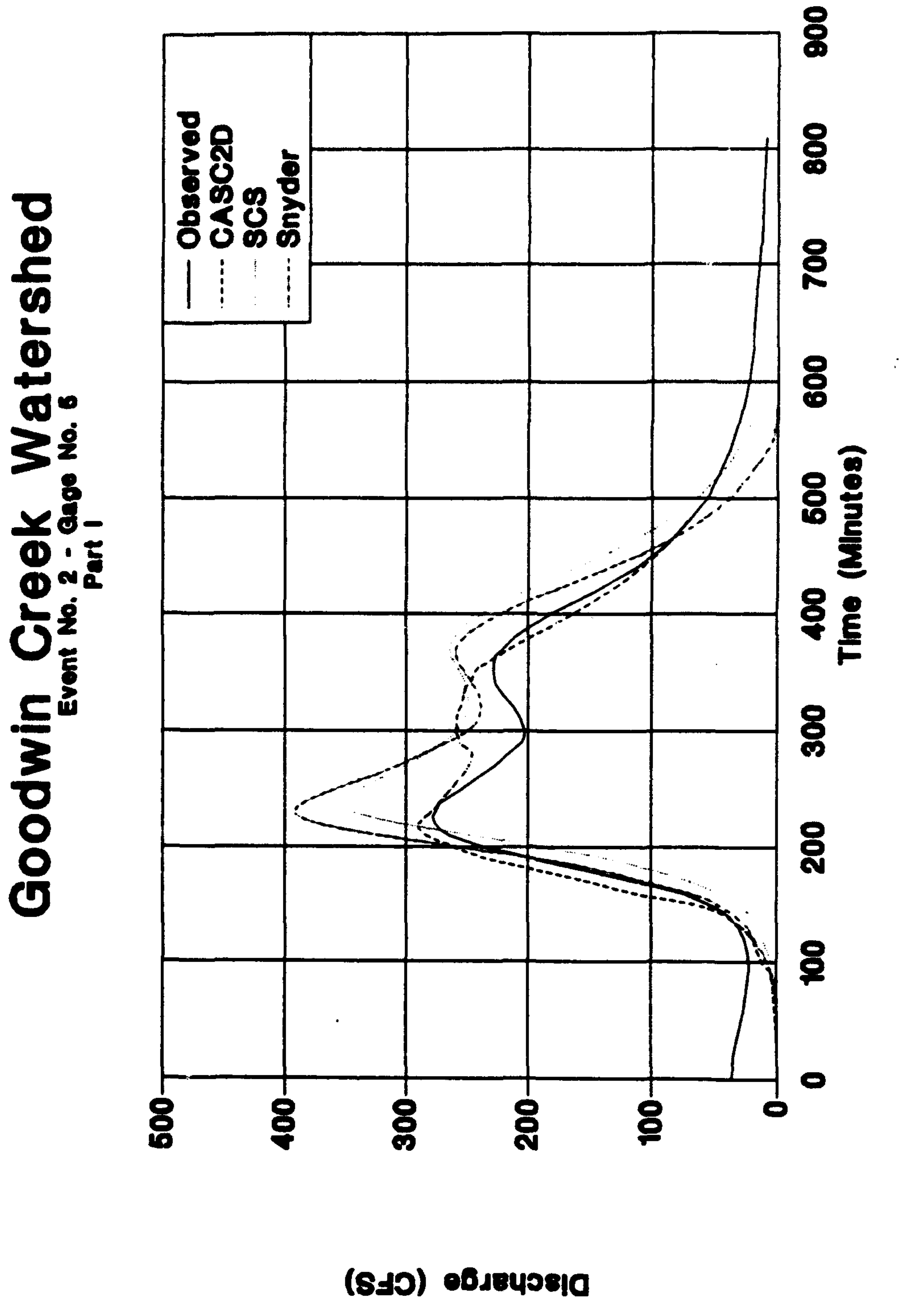

Figure A-11 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 2 at Gage 5 - Part I.

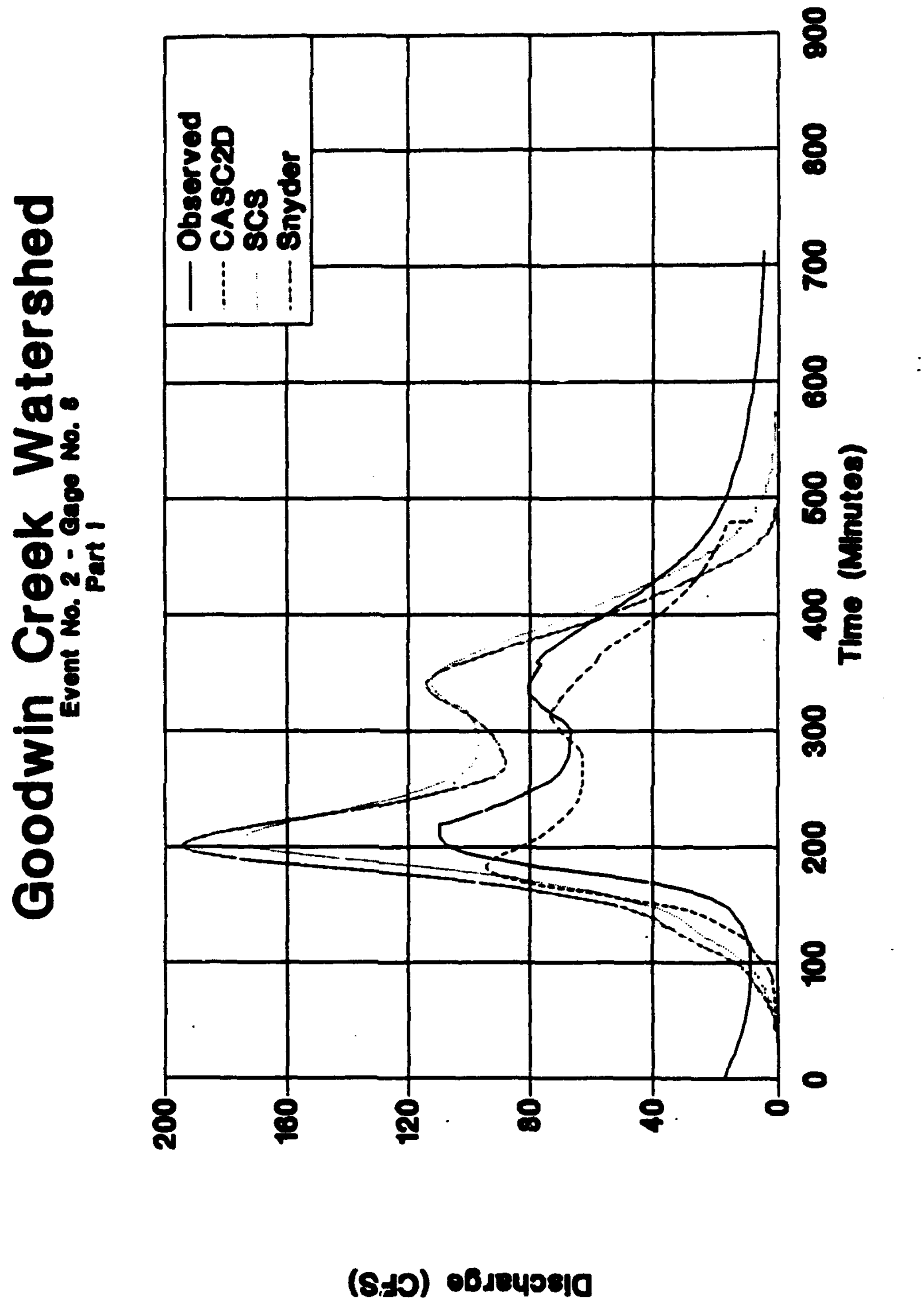

Figure A-12 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 2 at Gage 8 - Part I.

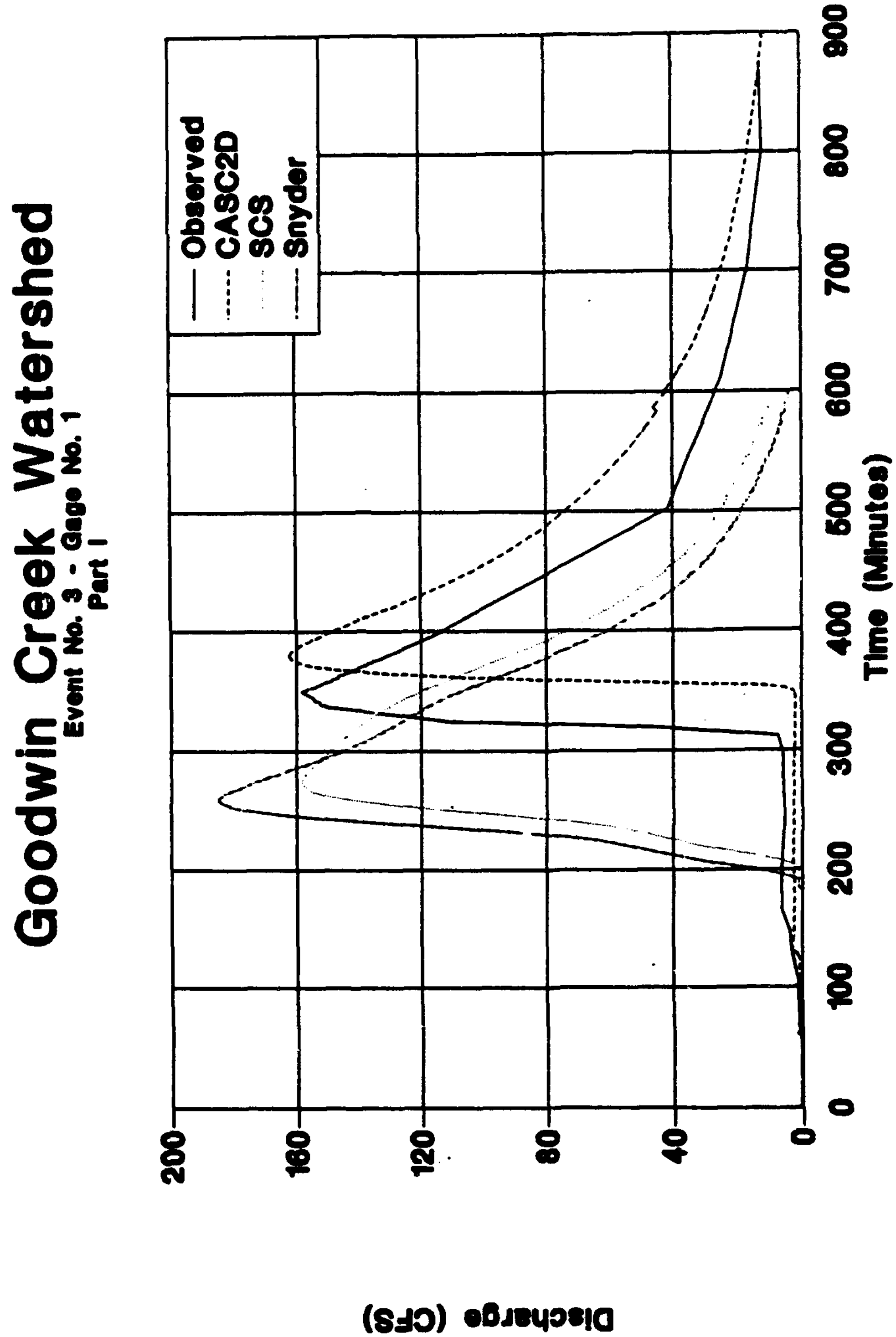

Figure A-13 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 3 at Gage 1 - Part I.

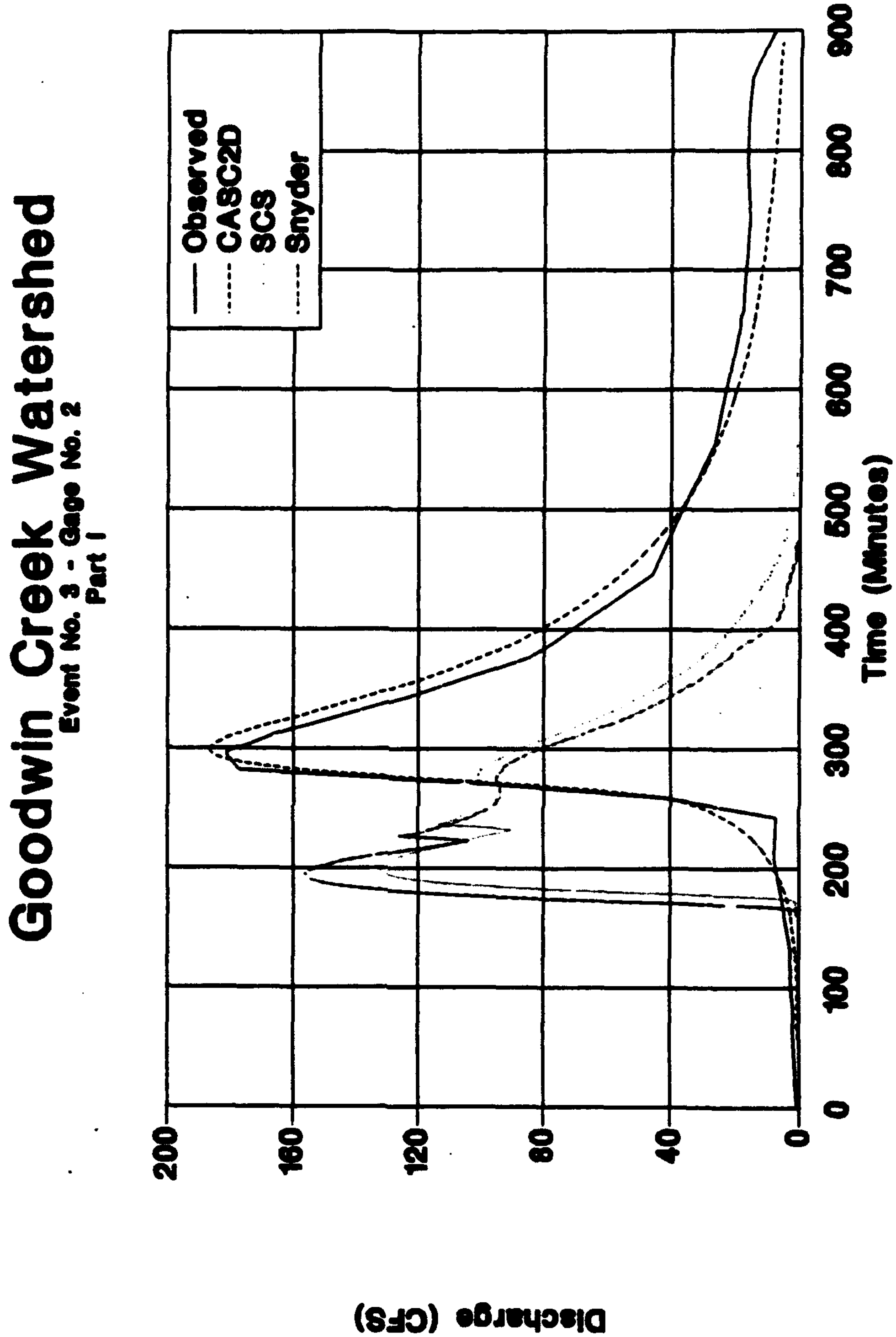

Figure A-14 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 3 at Gage 2 - Part I.

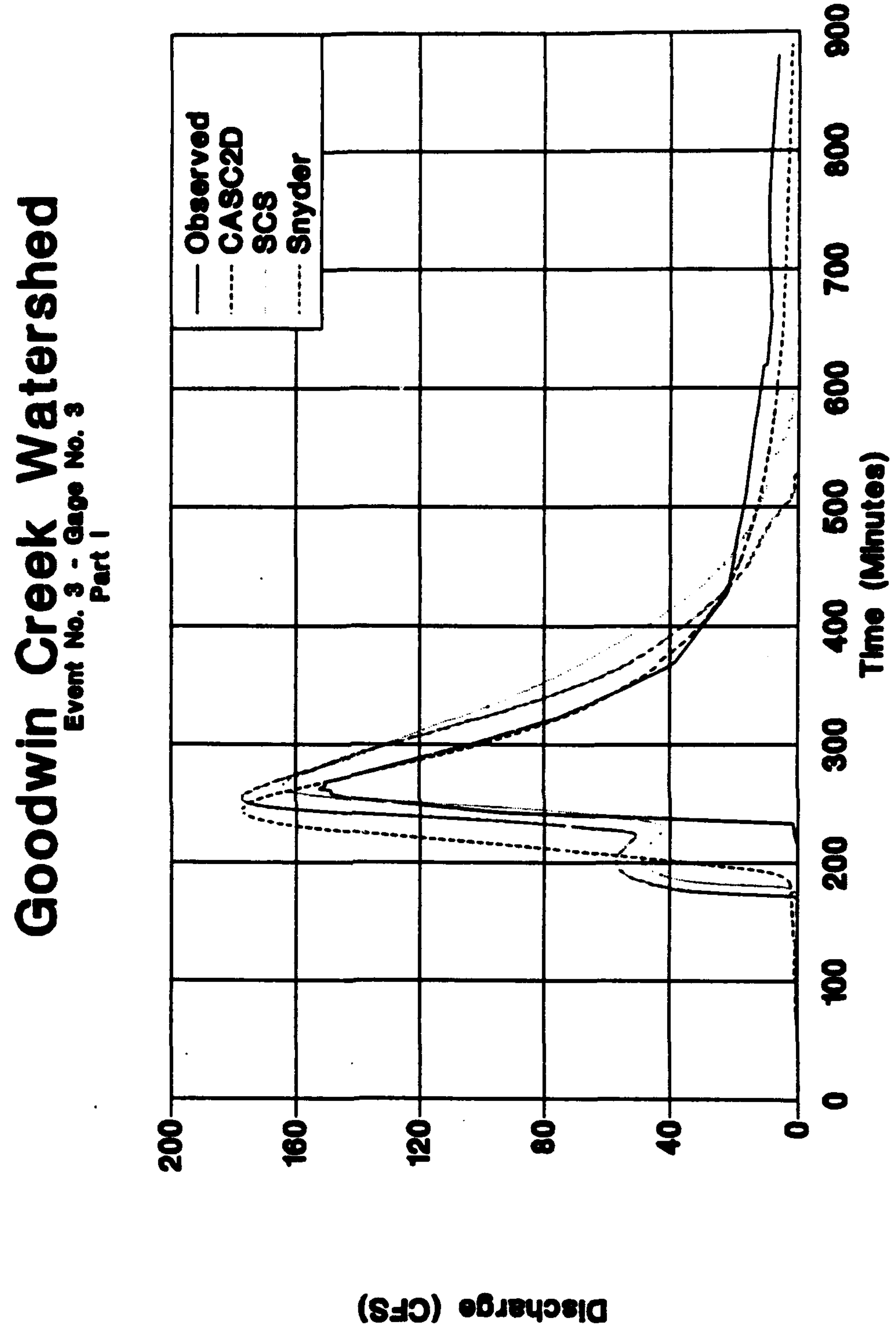

Figure A-15 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 3 at Gage 3 - Part I.

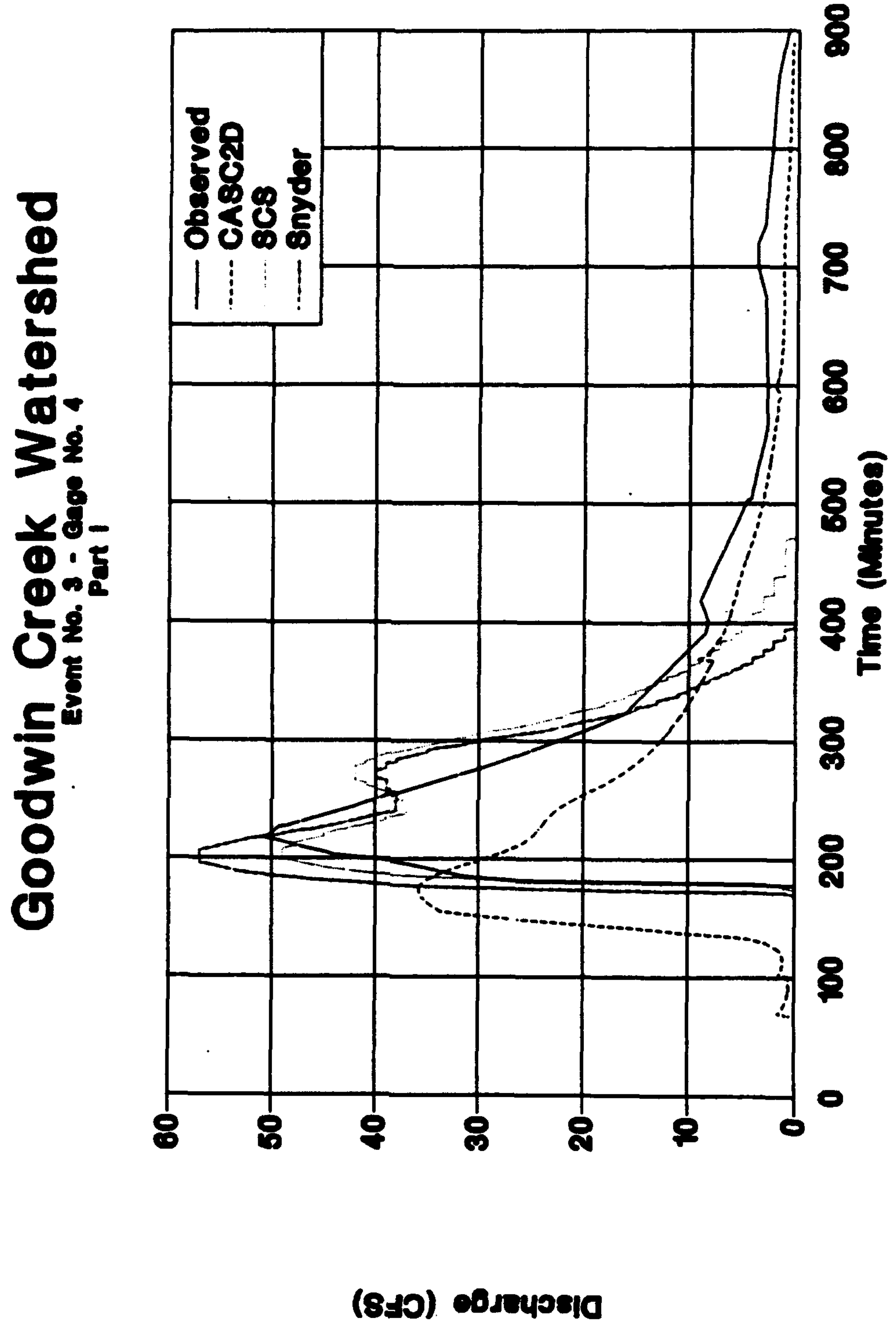

Figure A-16 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 3 at Gage 4 - Part I.

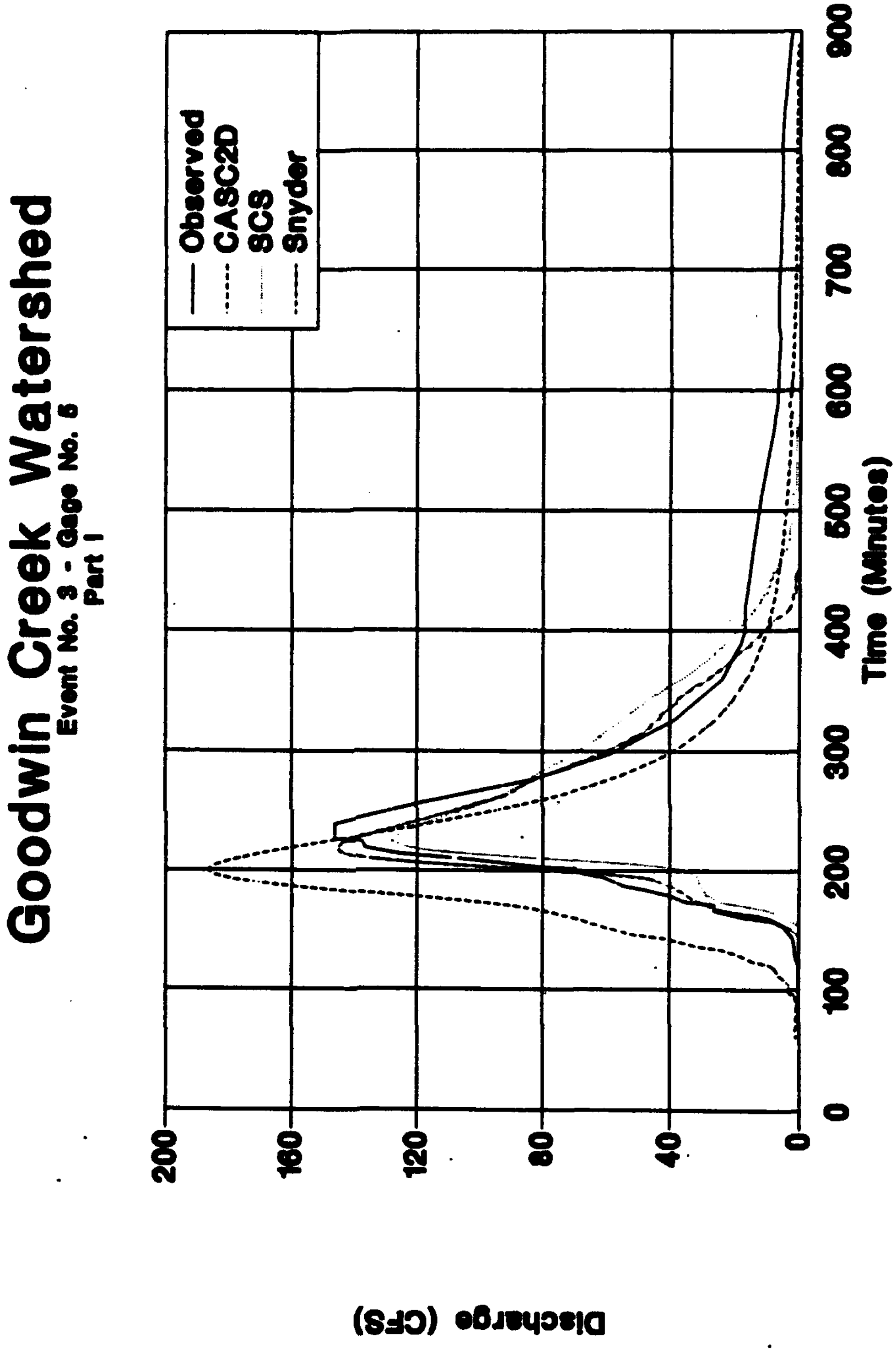

Figure A-17 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 3 at Gage 5 - Part I.

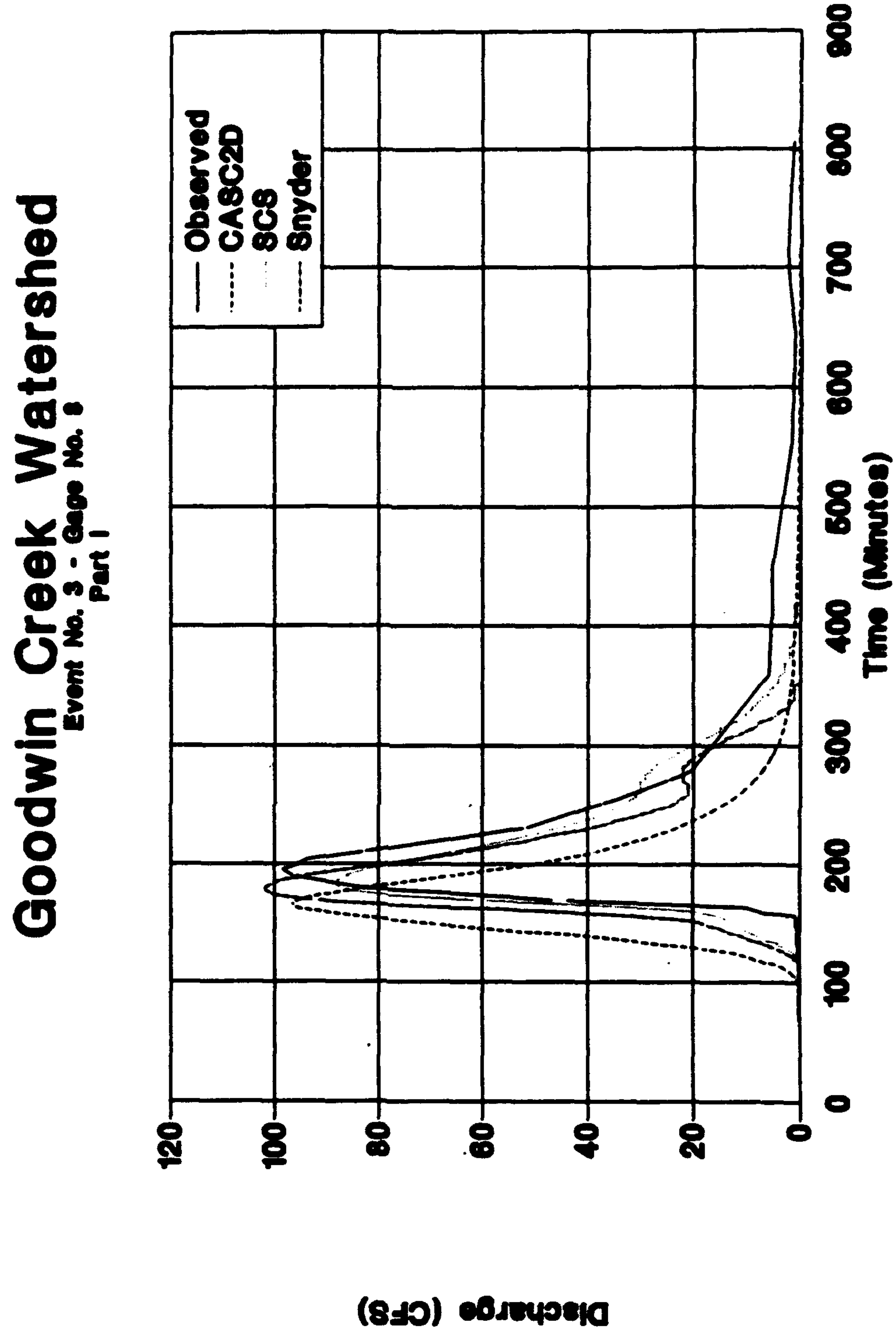

Figure A-18 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 3 at Gage 8 - Part I.

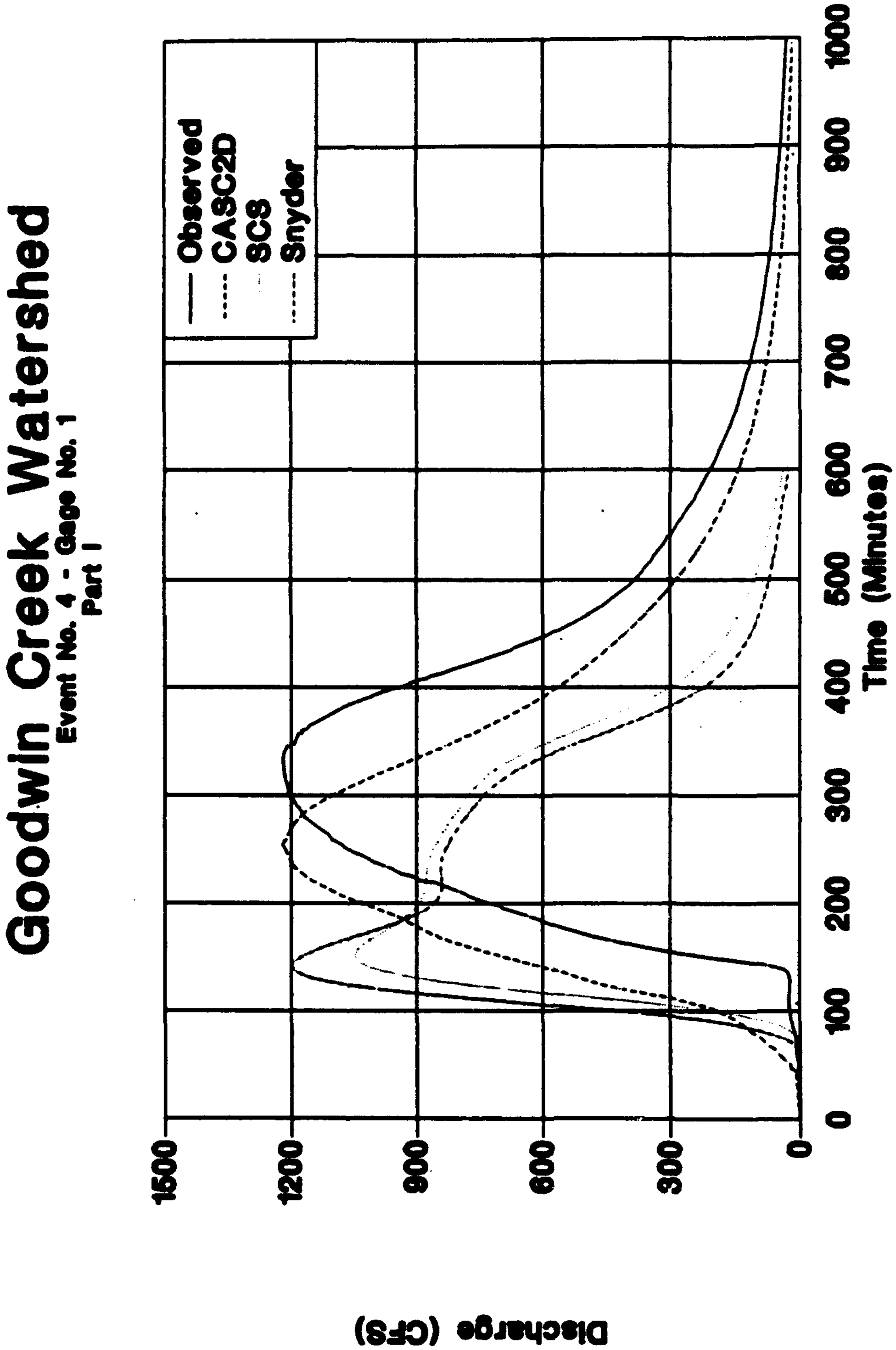

Figure A-19 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 4 at Gage 1 - Part I.

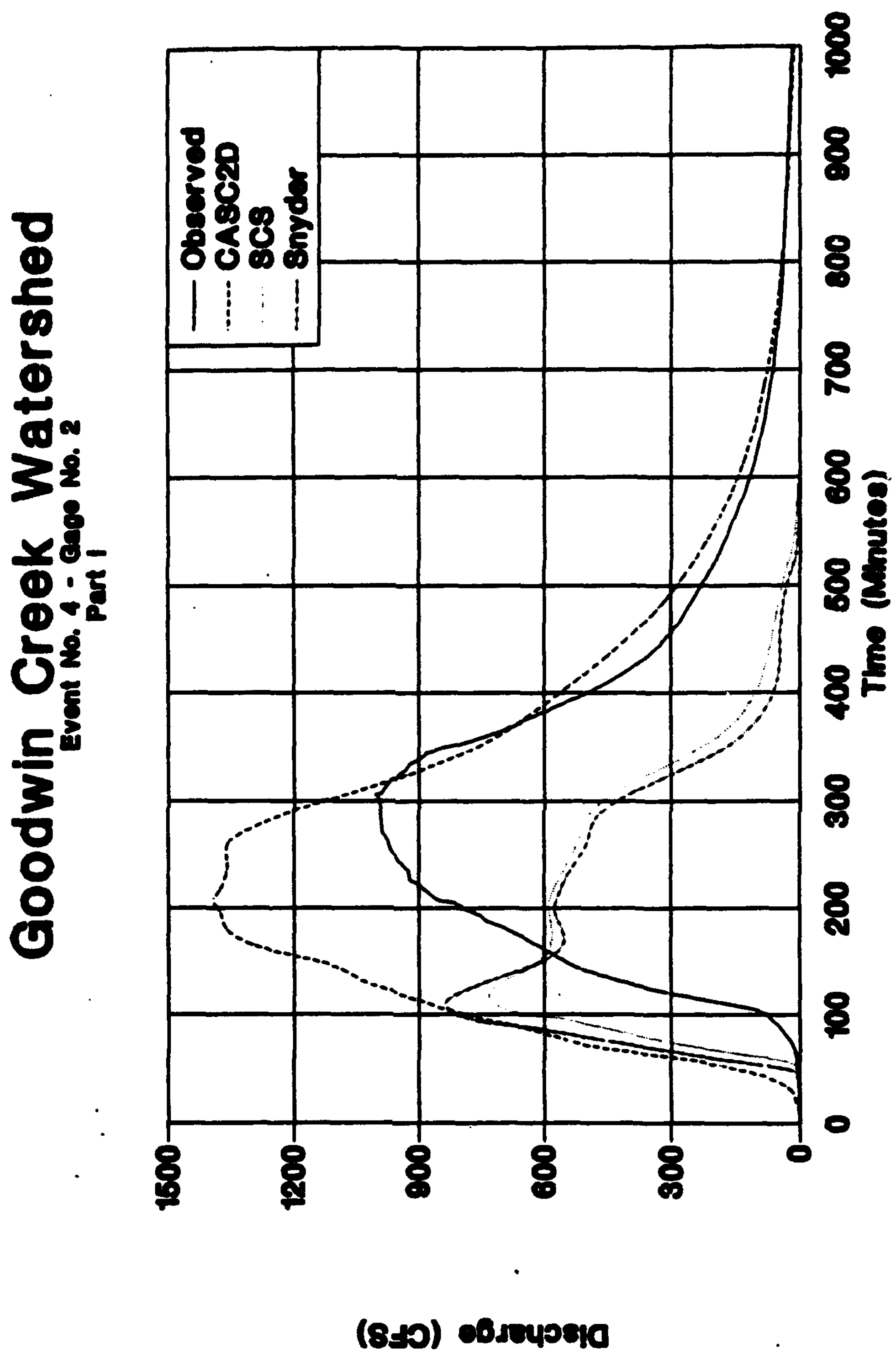

Figure A-20 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 4 at Gage 2 - Part I.

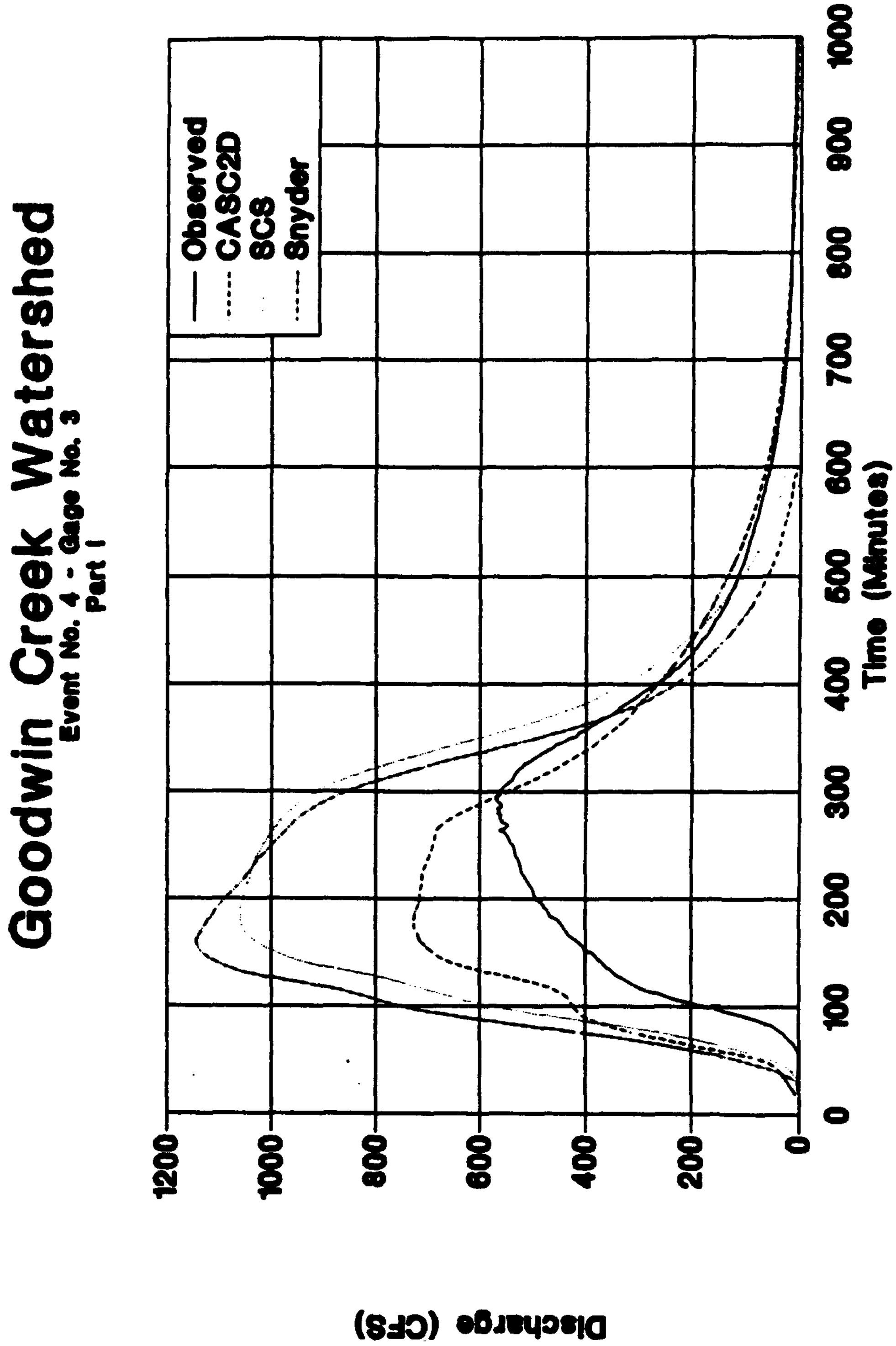

Figure A-21 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 4 at Gage 3 - Part I.

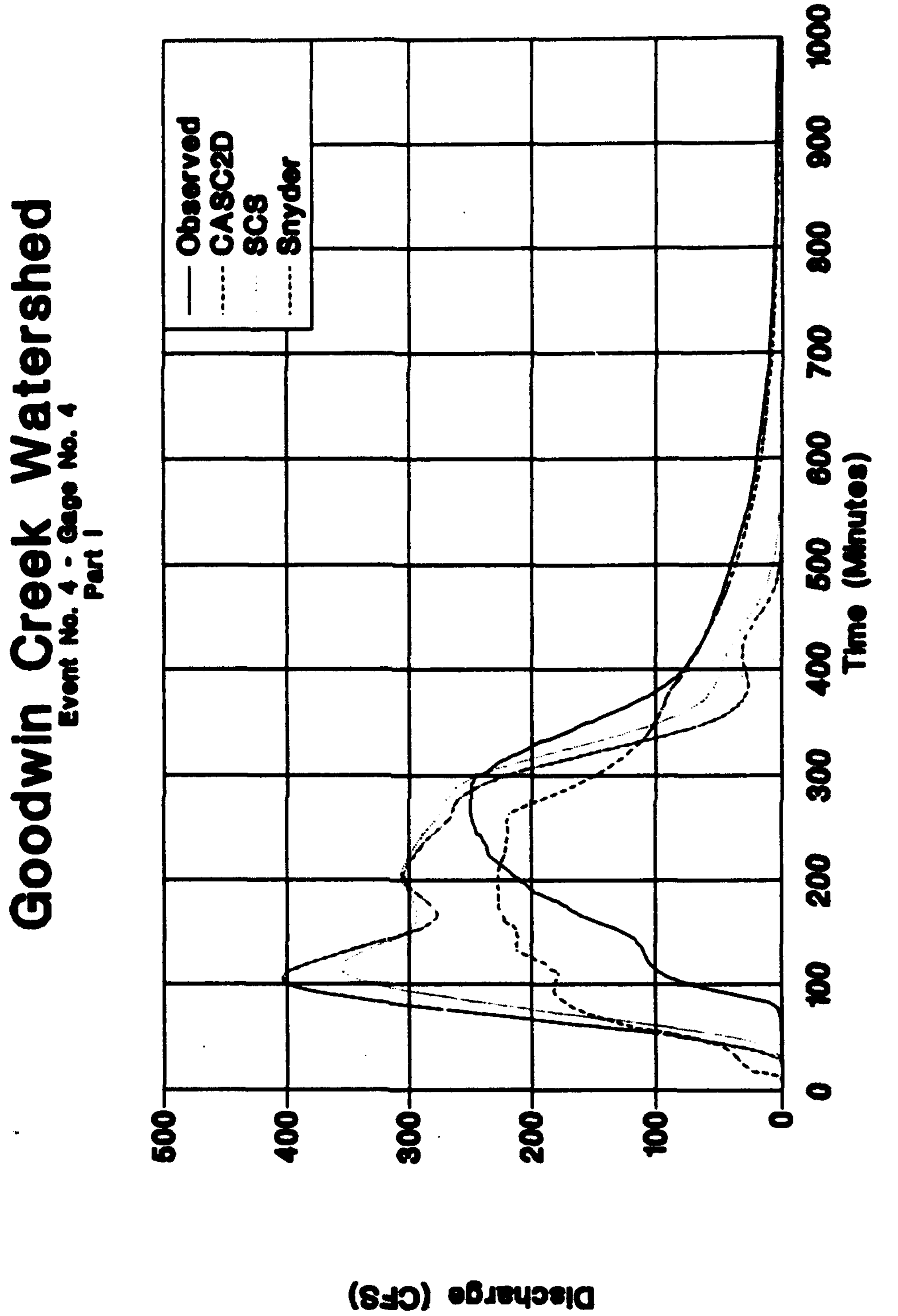

Figure A-22 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 4 at Gage 4 - Part I.

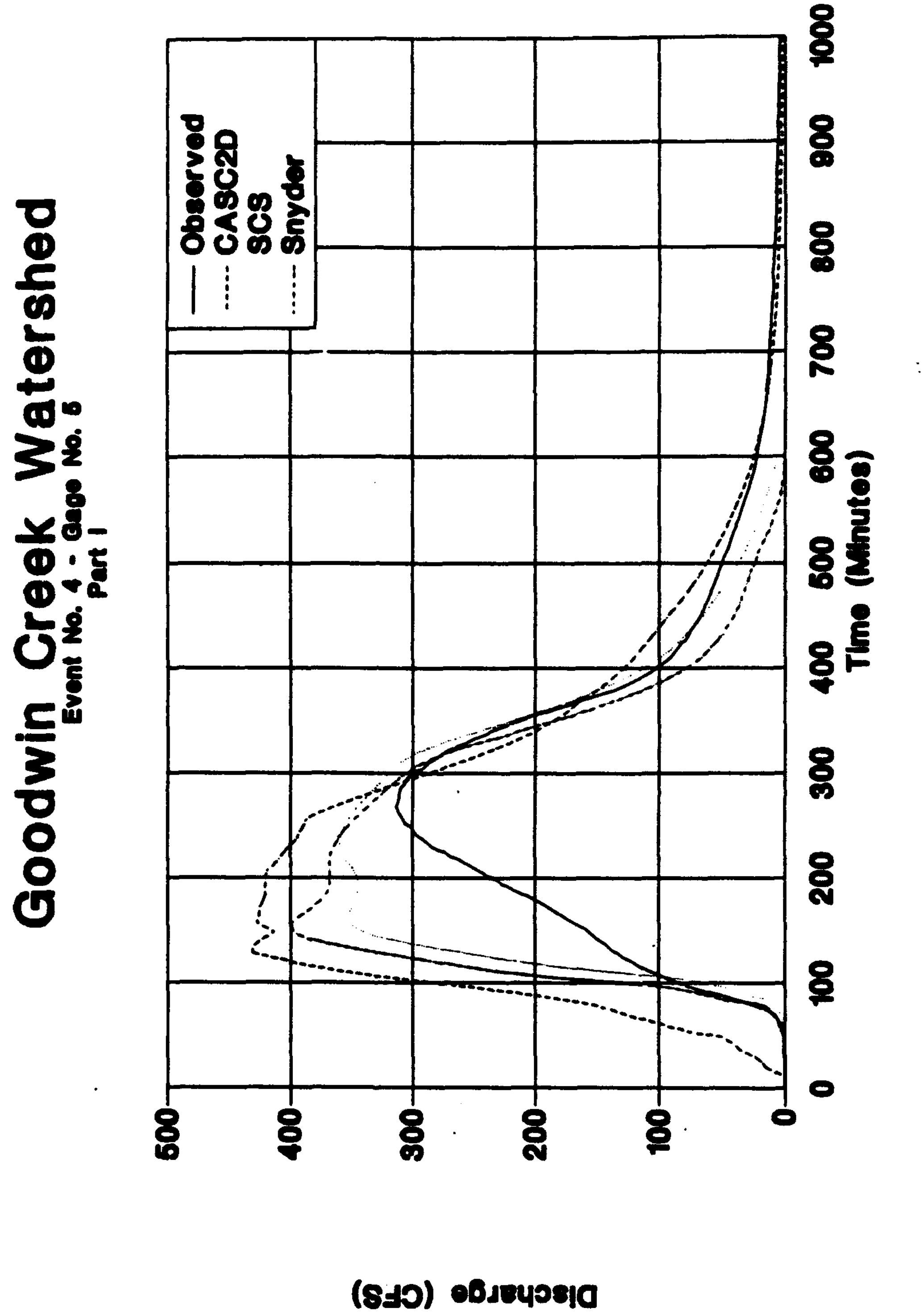

Figure A-23 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 4 at Gage 5 - Part I.

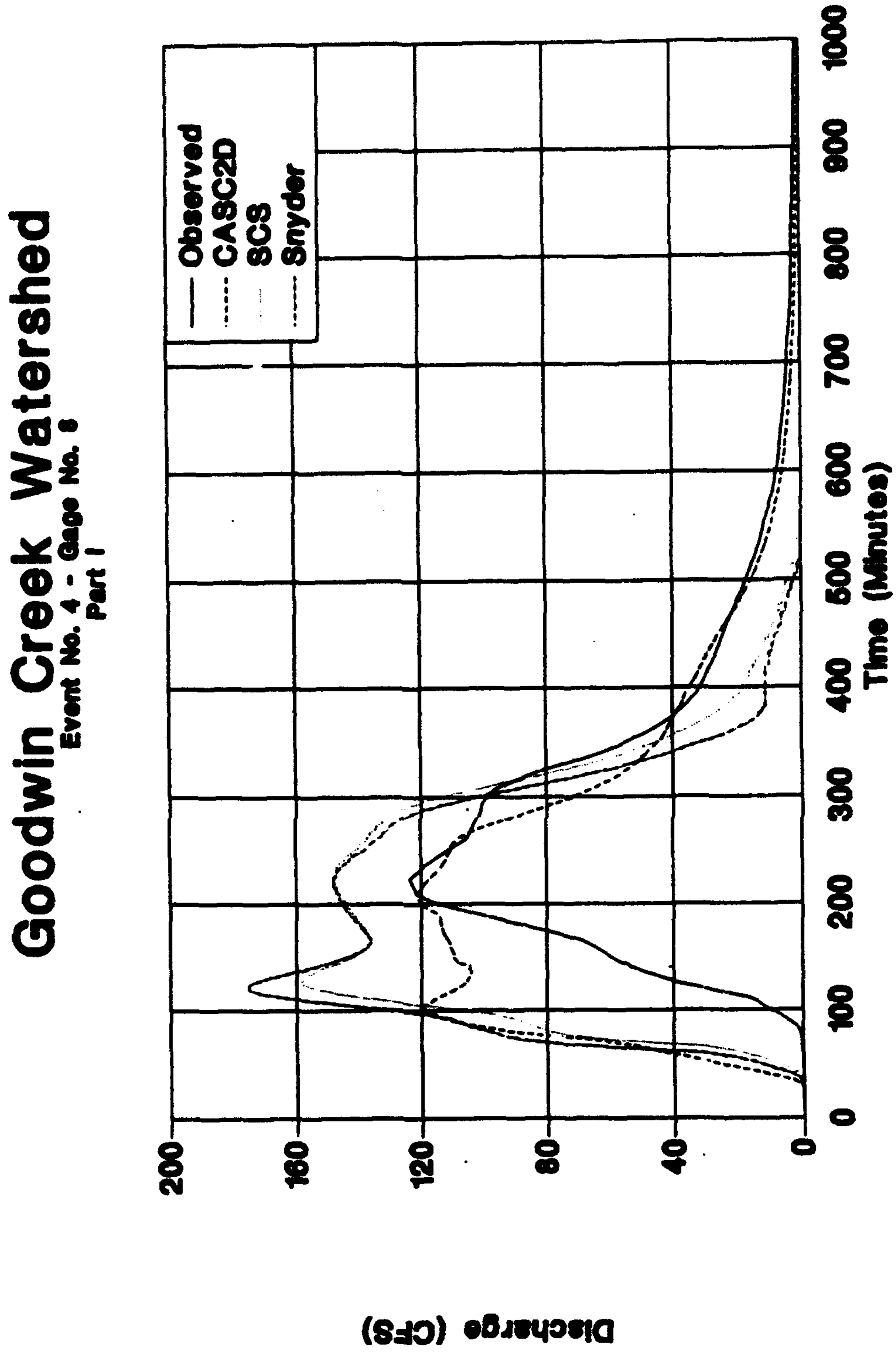

Figure A-24 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 4 at Gage 8 - Part I.

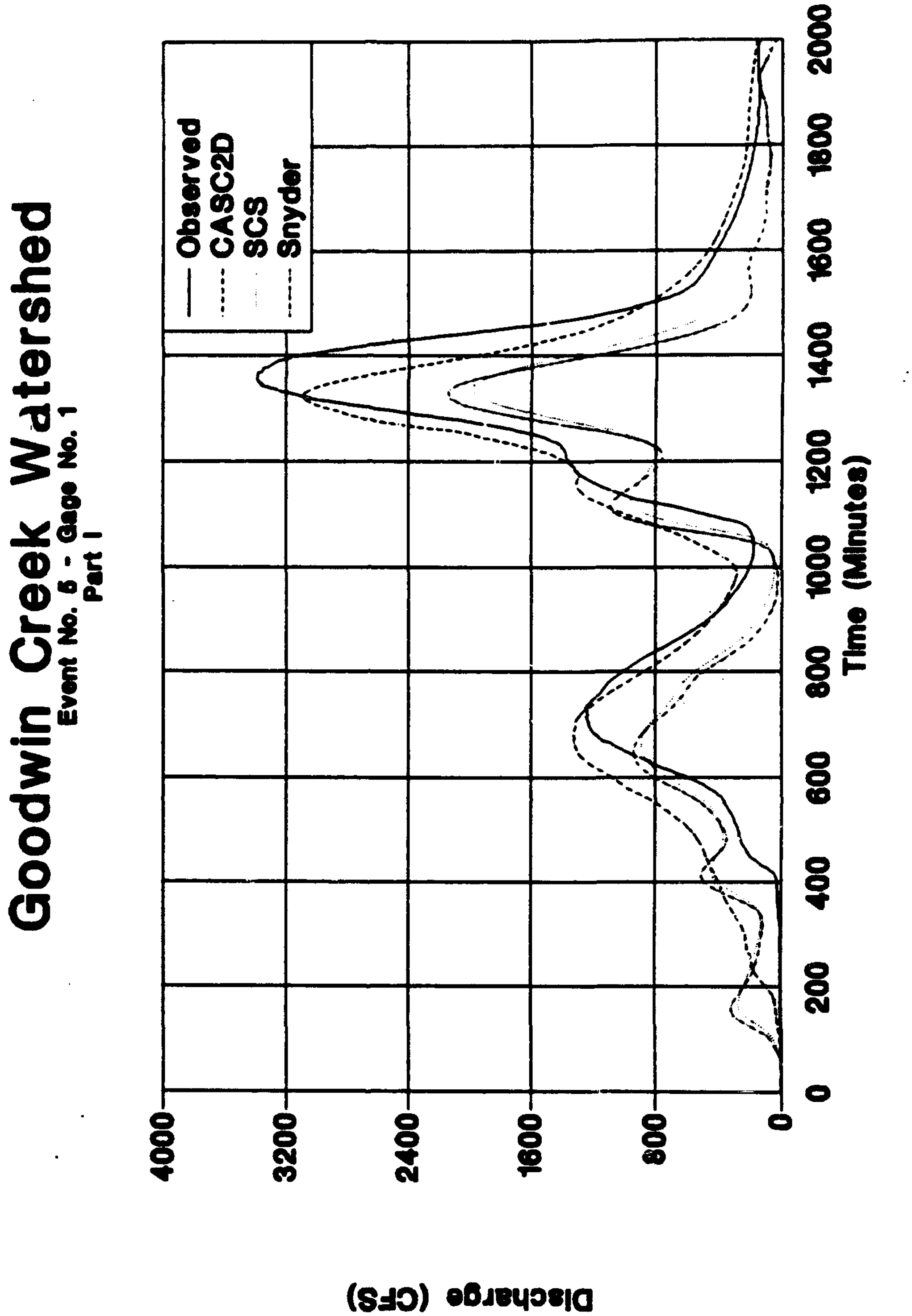

Figure A-25 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 5 at Gage 1 - Part I.

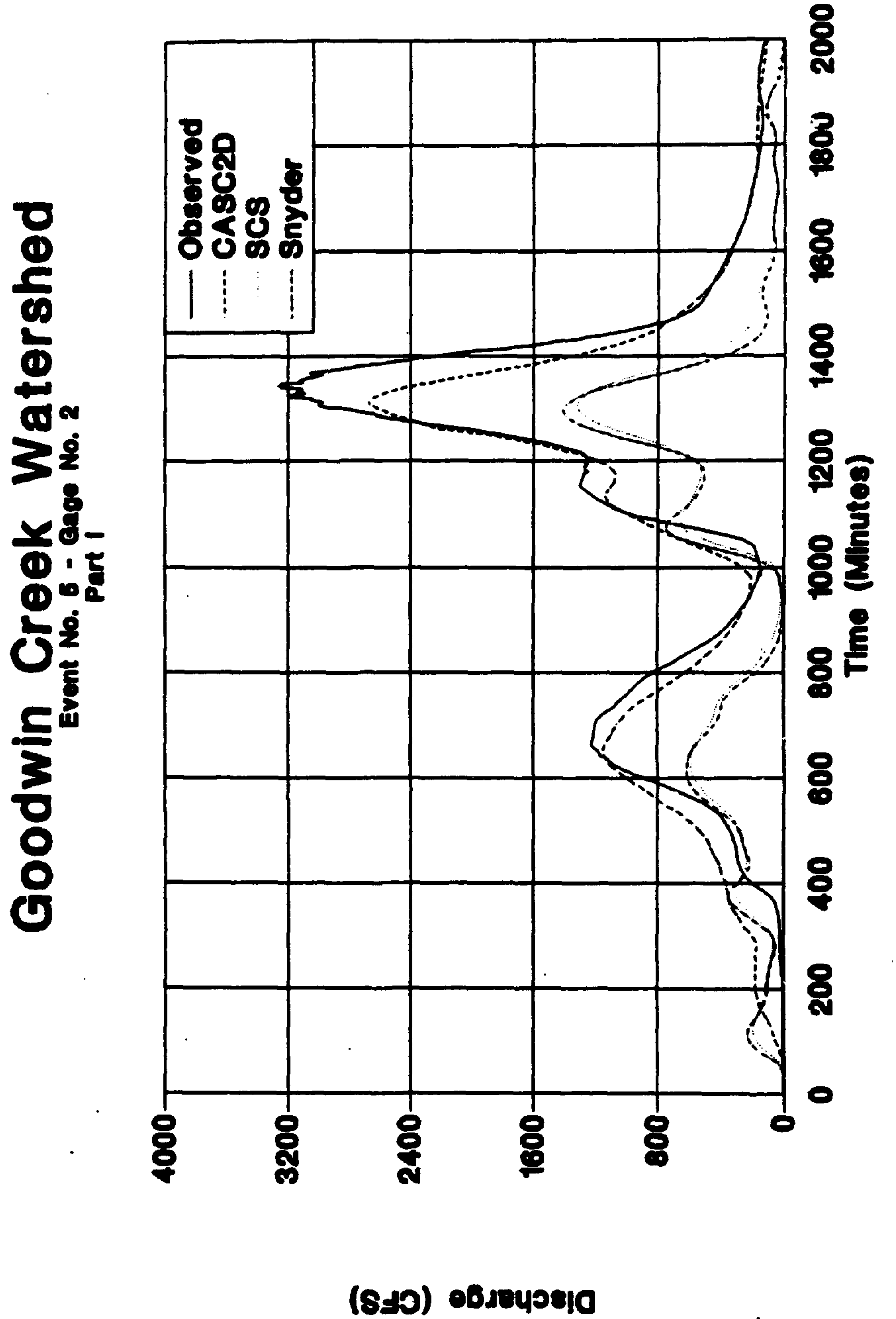

Figure A-26 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 5 at Gage 2 - Part I.

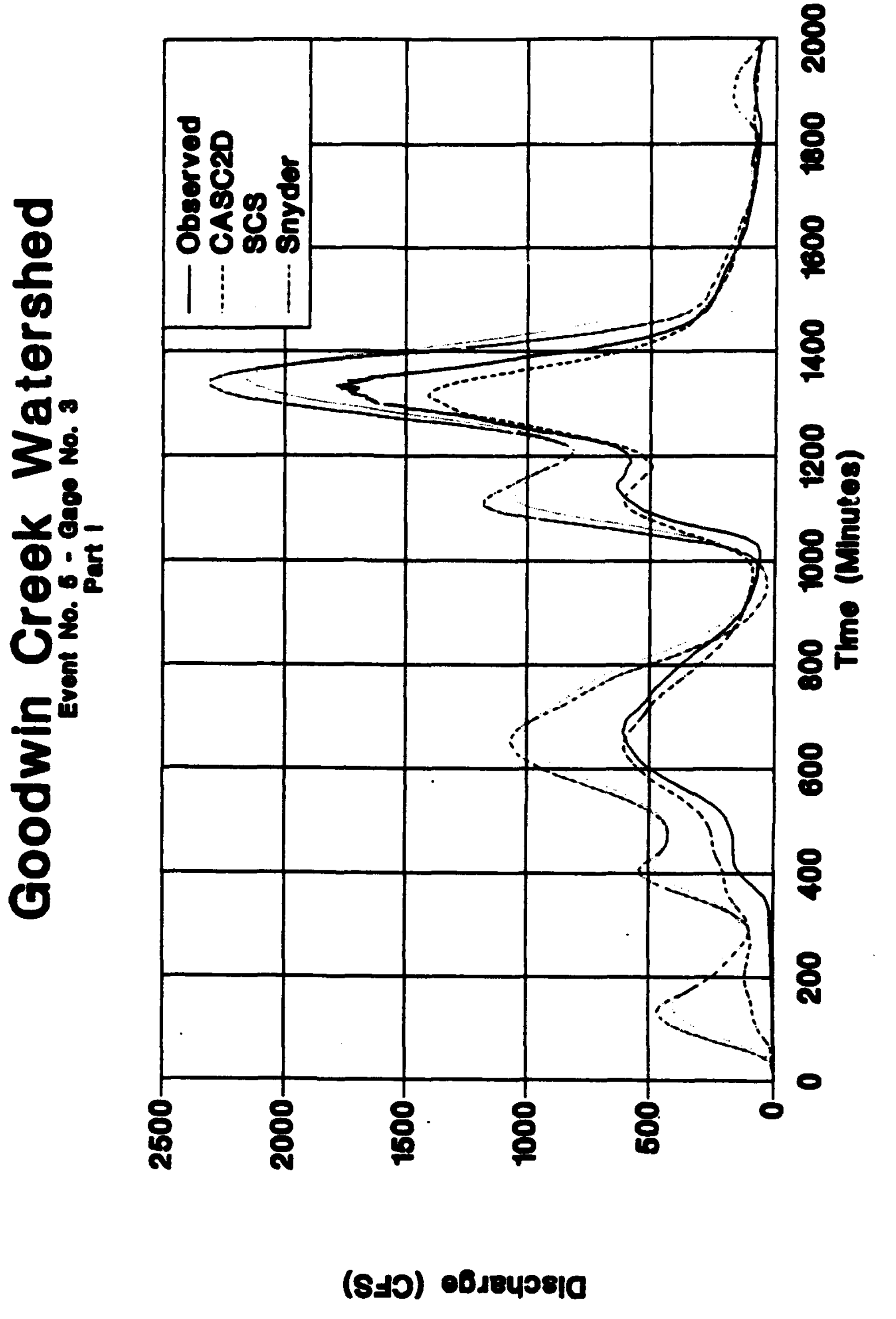

Figure A-27 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 5 at Gage 3 - Part I.

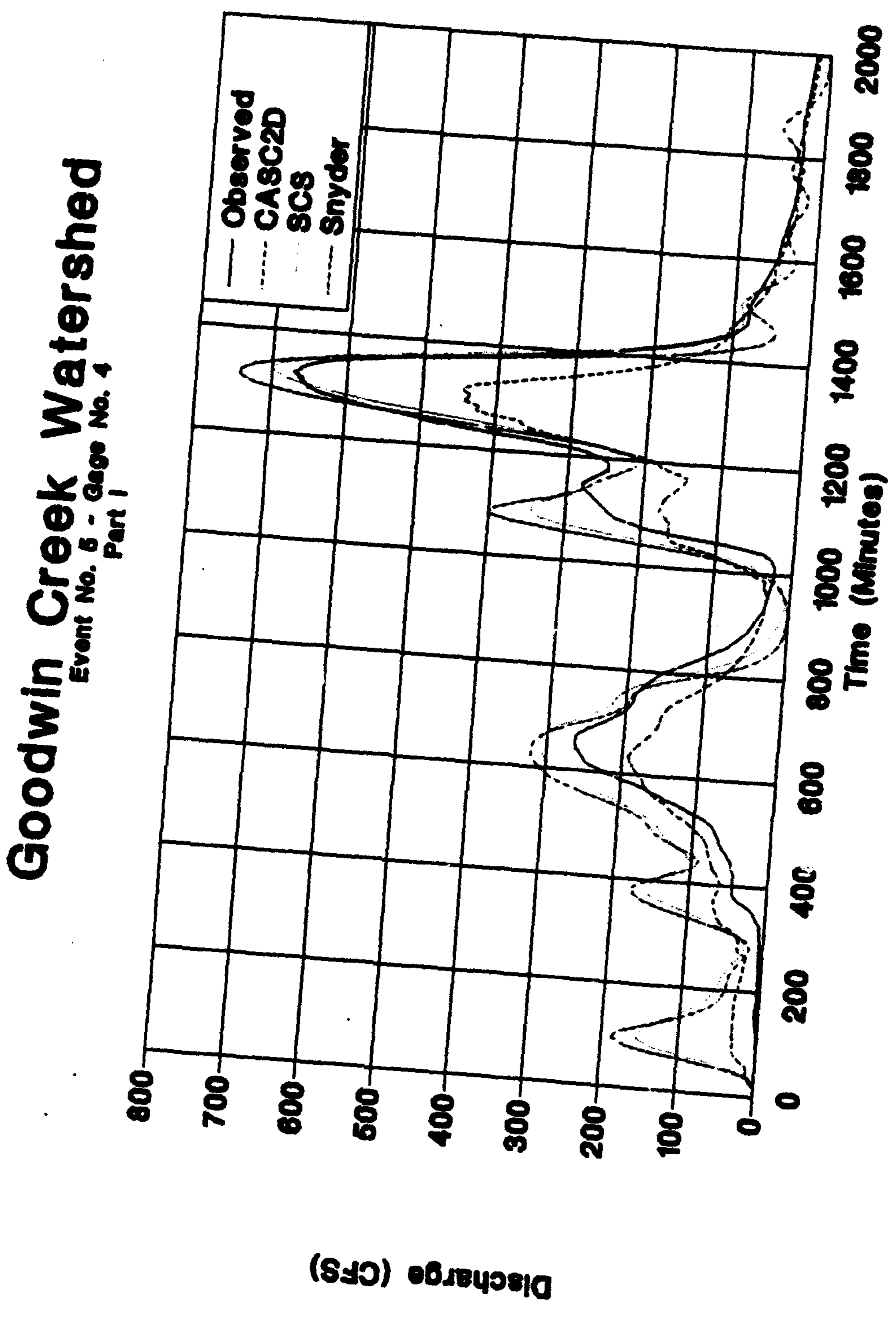

Figure A-28 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 5 at Gage 4 - Part I.

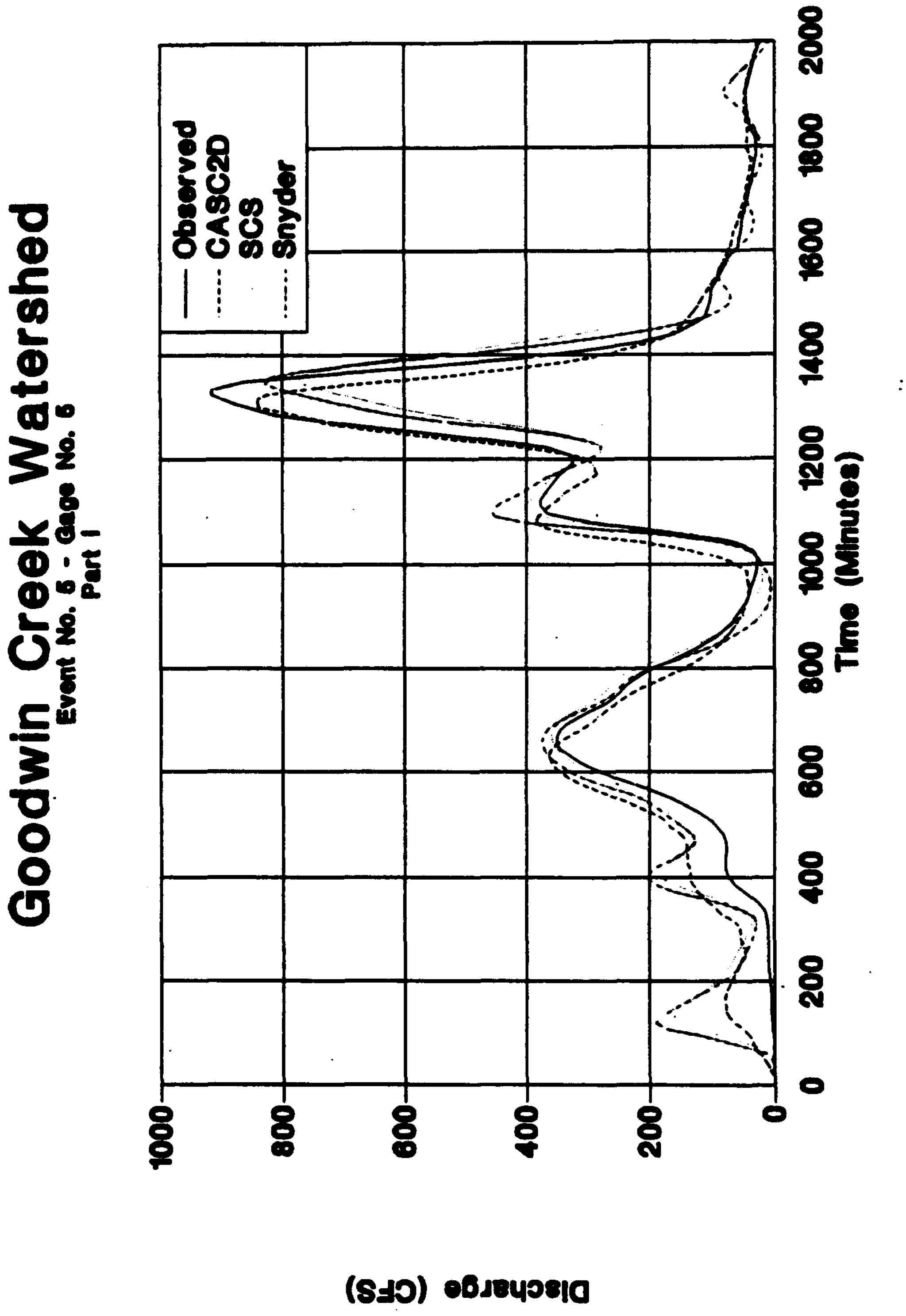

Figure A-29 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 5 at Gage 5 - Part I.

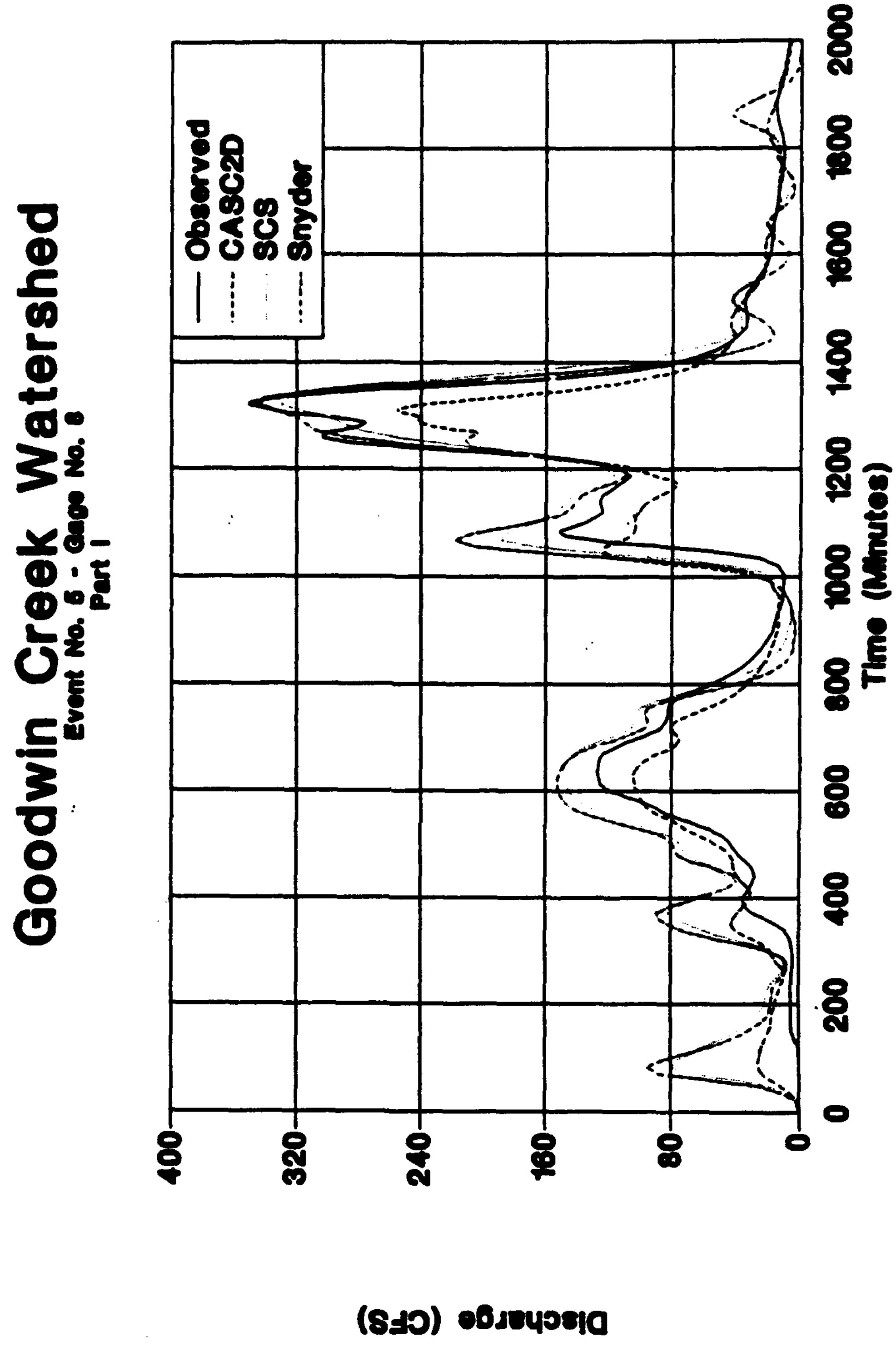

Figure A-30 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 5 at Gage 8 - Part I.

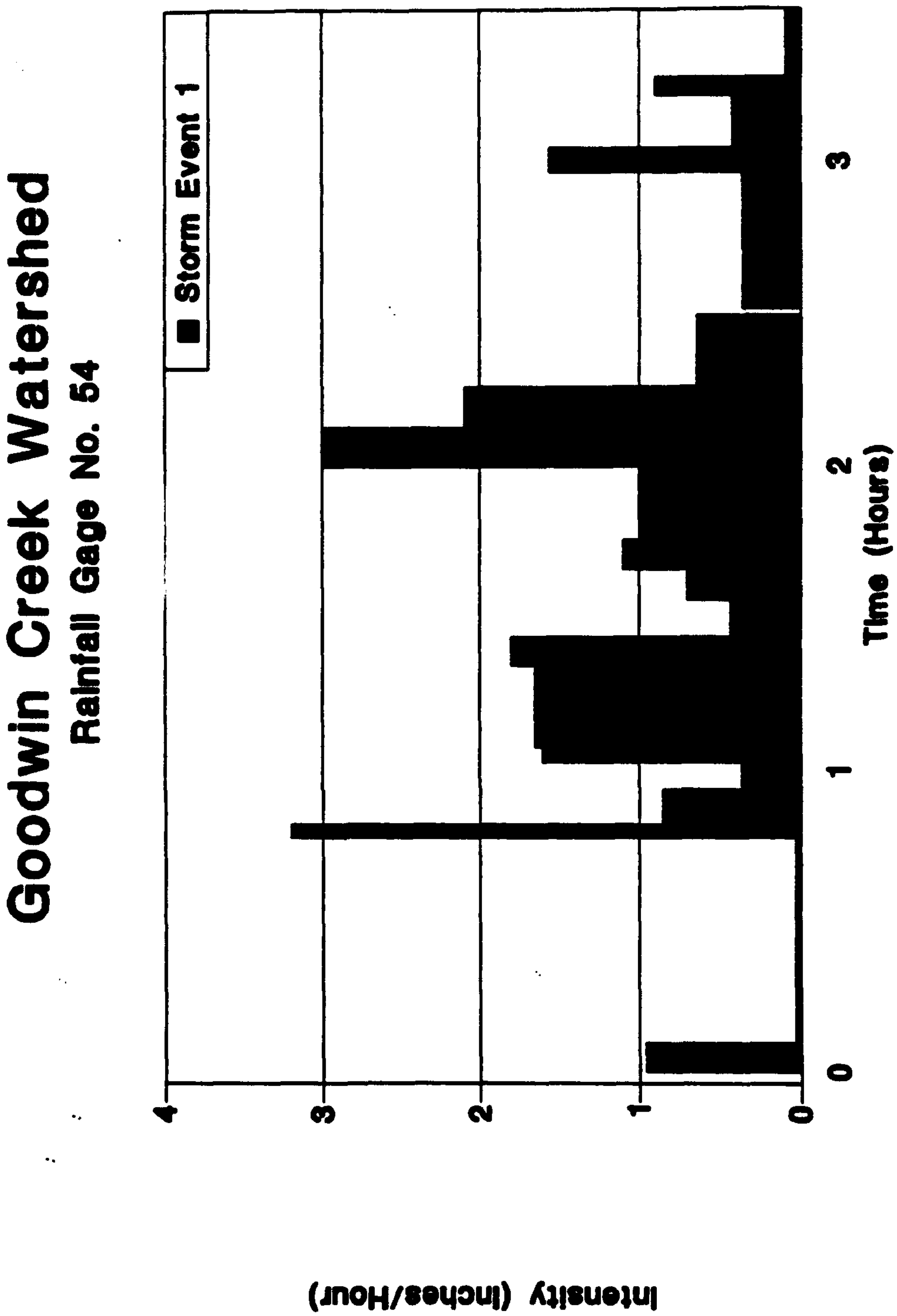

Figure A-31 - Storm Event No. 1 - Rainfall Hyetograph at Rainfall Gage No. 54

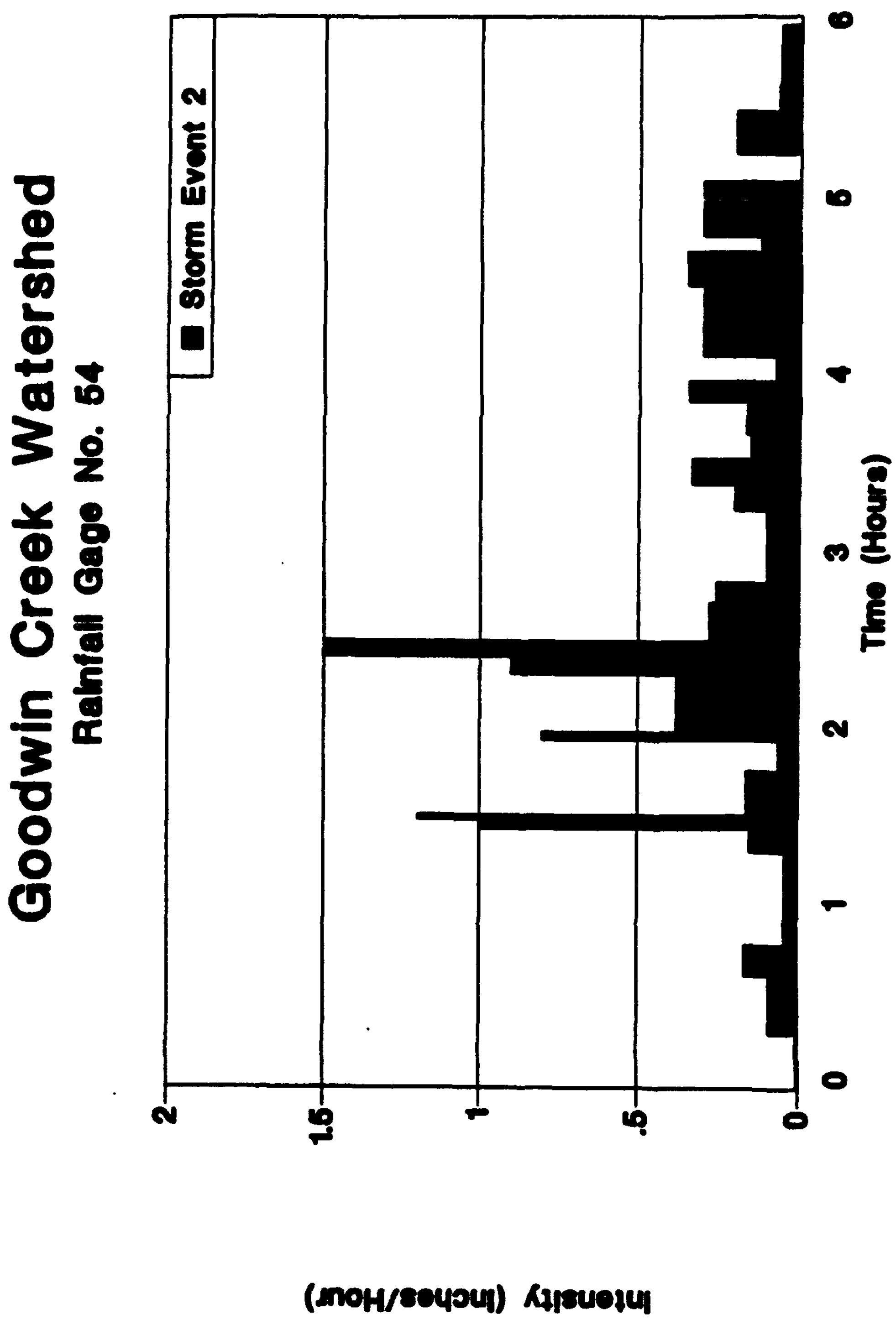

Figure A-32 - Storm Event No. 2 - Rainfall Hyetograph at Rainfall Gage No. 54

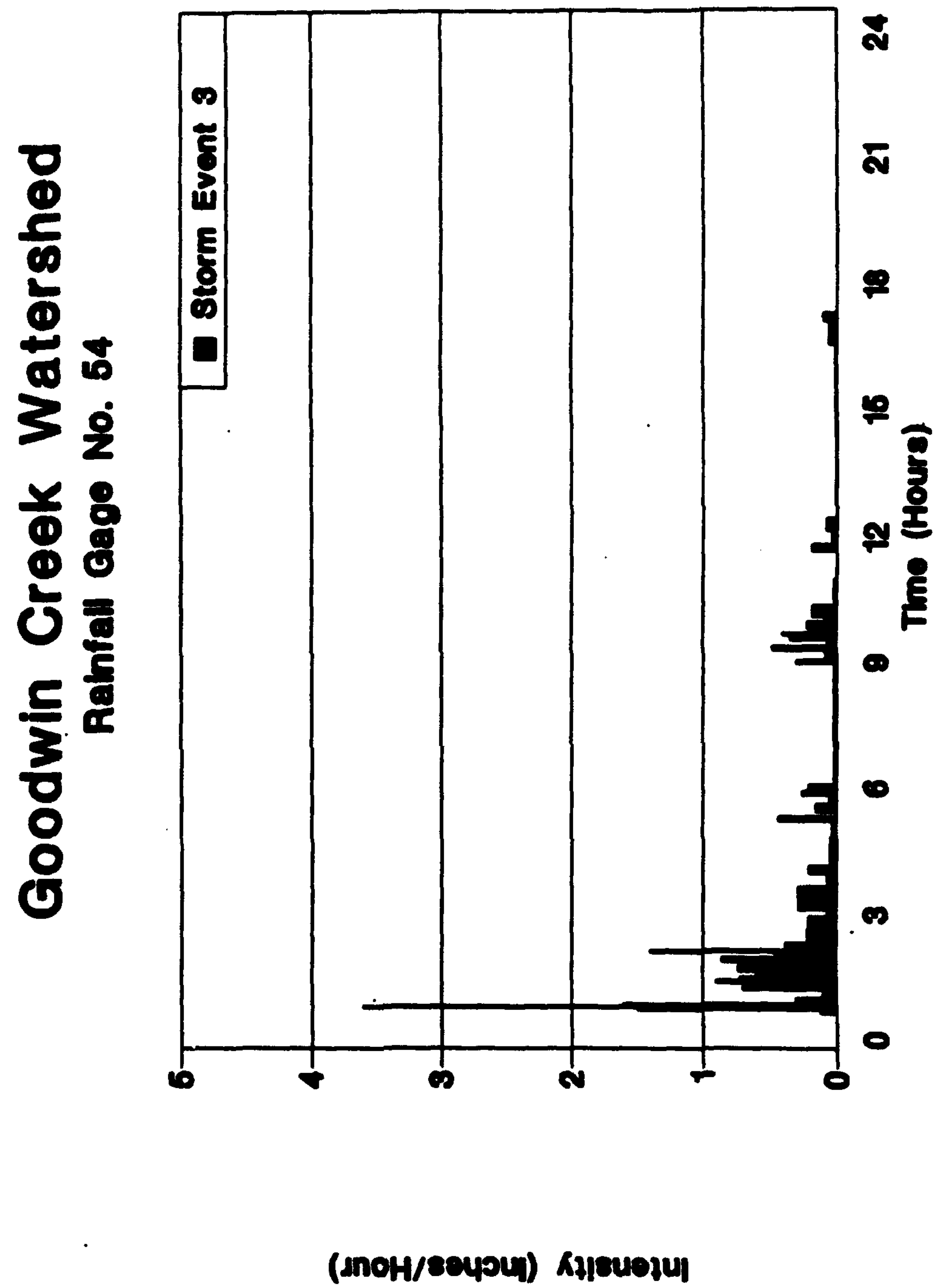

Figure A-33 - Storm Event No. 3 - Rainfall Hyetograph at Rainfall Gage No. 54

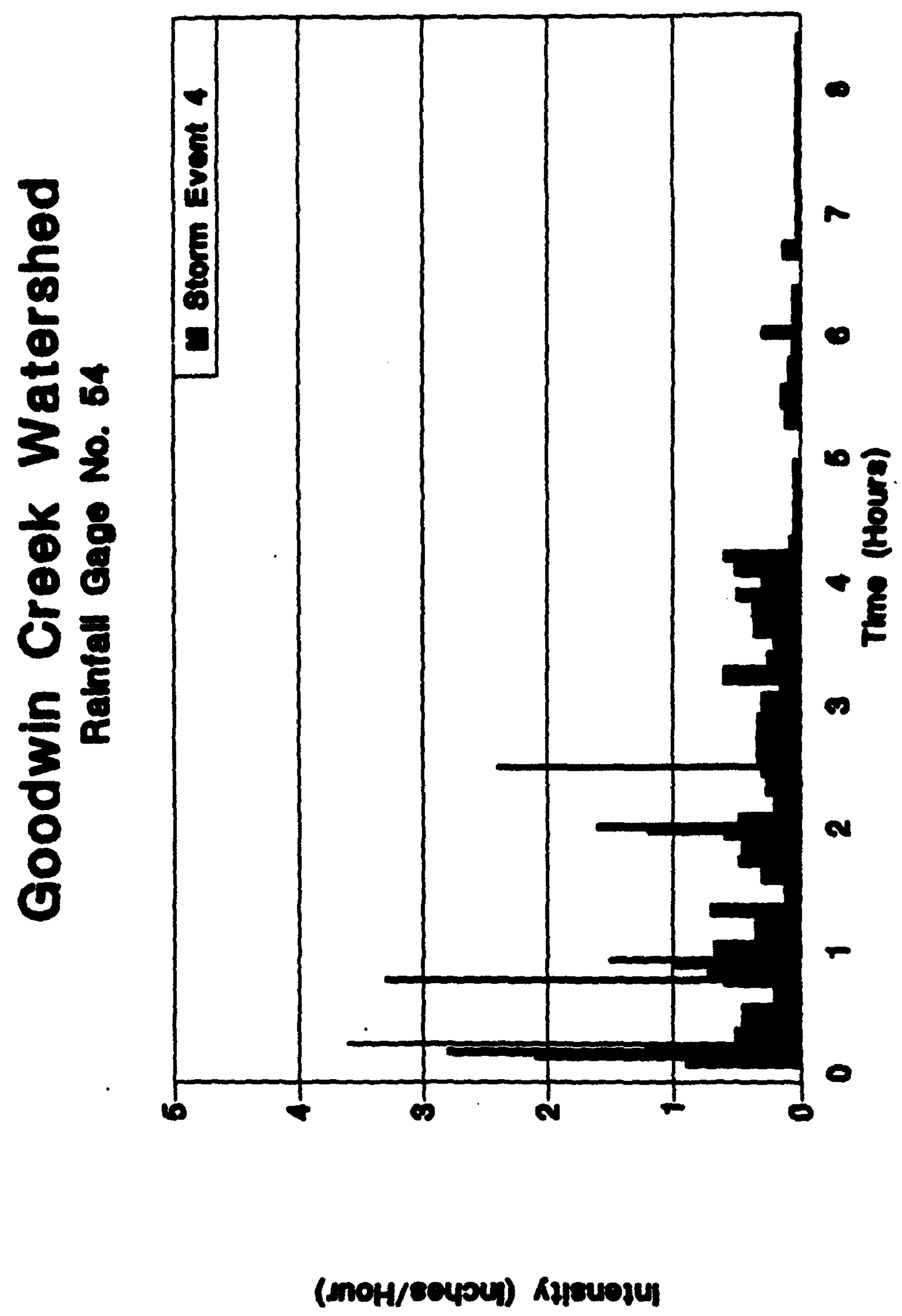

Figure A-34 - Storm Event No. 4 - Rainfall Hyetograph at Rainfall Gage No. 54

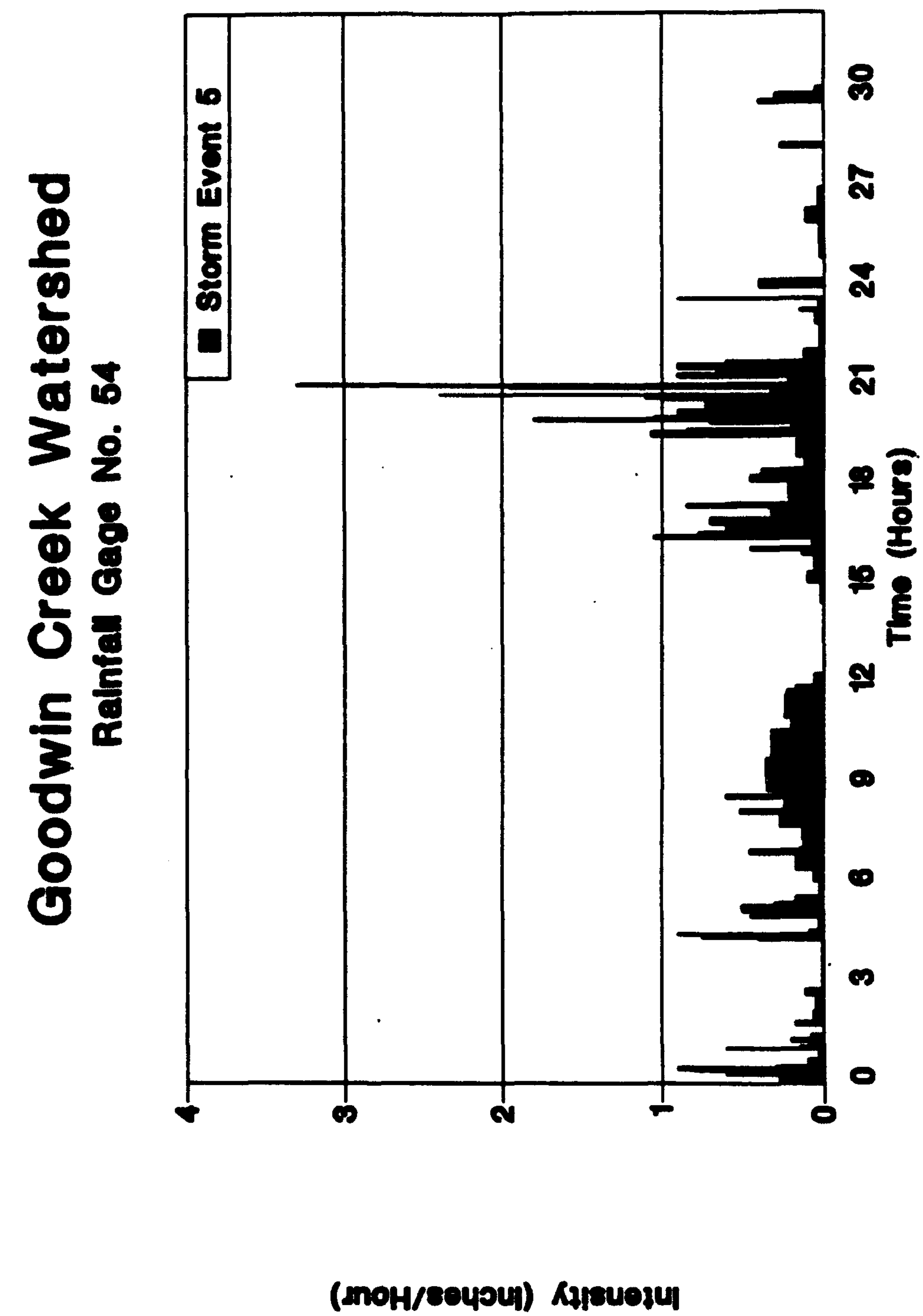

Figure A-35 - Storm Event No. 5 - Rainfall Hyetograph at Rainfall Gage No. 54

APPENDIX B - Tables and Hydrographs

for Simulation of Hypothetical Storm Events

Table B-1 - Total Runoff (Inches) - Part II

Discharge Gage No.	Computation Method	Storm Event 1	3
1	Observed	.70	.09
	CASC2D	.70	.14
	Snyder	.79	.09
2	Observed	.07	.095
	CASC2D	.61	.12
	Snyder	.63	.08
3	Observed	.39	.06
	CASC2D	.32	.07
	Snyder	.38	.08
4	Observed	.13	.02
	CASC2D	.11	.02
	Snyder	.11	.02
5	Observed	.22	.06
	CASC2D	.20	.05
	Snyder	.13	.05
8	Observed	.08	.03
	CASC2D	.06	.01
	Snyder	.05	.03

Table B-2 - Peak Flow (CFS) - Part II

Discharge Gage No.	Computation Method	Storm Event 1	3
1	Observed	1405	158
	CASC2D	1354	144
	Snyder	1936	176
2	Observed	1541	181
	CASC2D	1255	144
	Snyder	1604	205
3	Observed	1051	152
	CASC2D	726	108
	Snyder	1128	220
4	Observed	347	51
	CASC2D	244	53
	Snyder	447	72
5	Observed	560	146
	CASC2D	514	97
	Snyder	433	177
8	Observed	260	98
	CASC2D	151	43
	Snyder	249	116

Table B-3 - Time to Peak (Minutes) - Part II

Discharge Gage No.	Computation Method	Storm Event 1	3
1	Observed	266	350
	CASC2D	218	346
	Snyder	244	358
2	Observed	248	294
	CASC2D	198	274
	Snyder	228	290
3	Observed	218	262
	CASC2D	172	250
	Snyder	220	244
4	Observed	206	218
	CASC2D	150	164
	Snyder	192	202
5	Observed	202	226
	CASC2D	154	204
	Snyder	208	214
8	Observed	192	194
	CASC2D	150	162
	Snyder	176	176

Table B-4 - Objective Function (CFS) - Part II

Discharge Gage No.	Computation Method	Storm Event 1	3
1	Observed	---	---
	CASC2D	479	53
	Snyder	397	19
2	Observed	---	---
	CASC2D	491	59
	Snyder	221	11
3	Observed	---	---
	CASC2D	284	41
	Snyder	67	54
4	Observed	---	---
	CASC2D	119	22
	Snyder	97	13
5	Observed	---	---
	CASC2D	201	29
	Snyder	84	21
8	Observed	---	---
	CASC2D	79	25
	Snyder	41	26

Table B-5 - Standard Error (CFS) - Part II

Discharge Gage No.	Computation Method	Storm Event 1	3
1	Observed	---	---
	CASC2D	364	34
	Snyder	254	16
2	Observed	---	---
	CASC2D	400	40
	Snyder	176	10
3	Observed	---	---
	CASC2D	224	26
	Snyder	50	29
4	Observed	---	---
	CASC2D	95	13
	Snyder	65	8
5	Observed	---	---
	CASC2D	146	21
	Snyder	71	13
8	Observed	---	---
	CASC2D	65	21
	Snyder	31	14

Table B-6 - Average Absolute Error (CFS) - Part II

Discharge Gage No.	Computation Method	Storm Event 1	3
1	Observed	---	---
	CASC2D	227	17
	Snyder	143	9
2	Observed	---	---
	CASC2D	260	19
	Snyder	118	9
3	Observed	---	---
	CASC2D	142	13
	Snyder	35	17
4	Observed	---	---
	CASC2D	61	7
	Snyder	39	5
5	Observed	---	---
	CASC2D	92	13
	Snyder	44	8
8	Observed	---	---
	CASC2D	41	13
	Snyder	19	7

Table B-7 - Average Percent Absolute Error (%) - Part II

Discharge Gage No.	Computation Method	Storm Event 1	3
1	Observed	---	---
	CASC2D	224	212
	Snyder	71	52
2	Observed	---	---
	CASC2D	2481	229
	Snyder	99	60
3	Observed	---	---
	CASC2D	1783	23446
	Snyder	71	14268
4	Observed	---	---
	CASC2D	1776	357
	Snyder	110	120
5	Observed	---	---
	CASC2D	36472	2048
	Snyder	76	78
8	Observed	---	---
	CASC2D	8042	1789
	Snyder	86	266

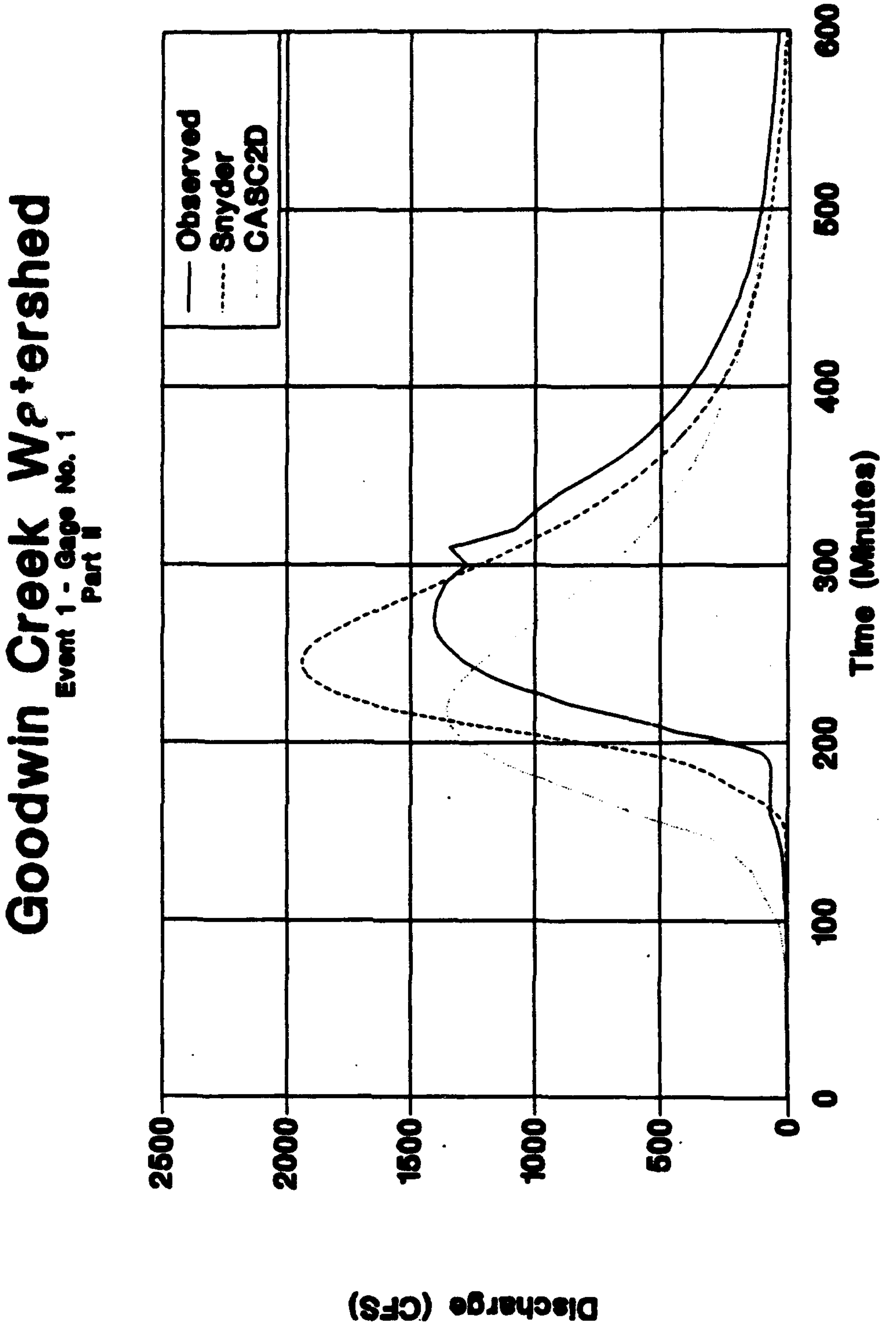

Figure B-1 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 1 at Gage 1 - Part II.

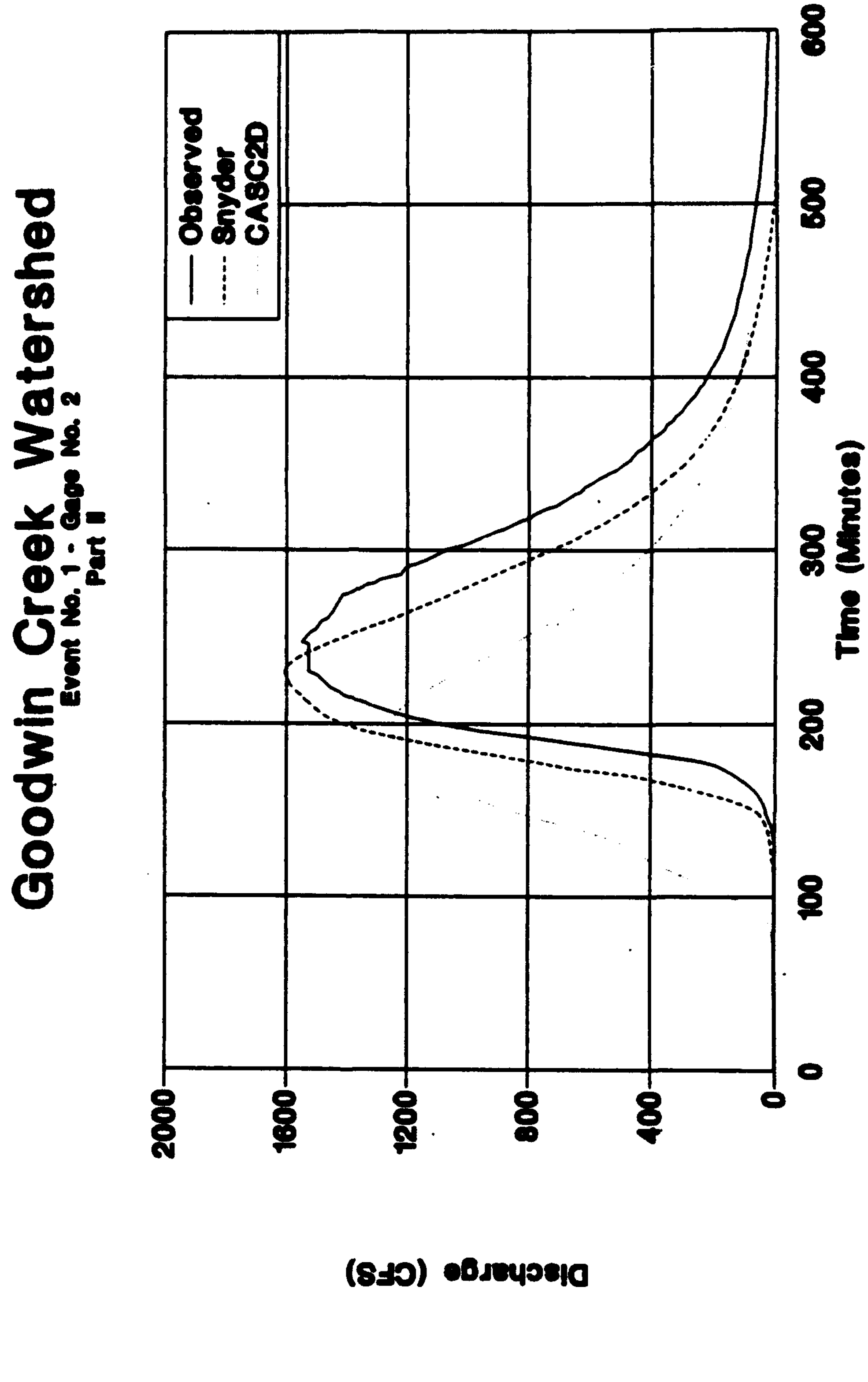

Figure B-2 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 1 at Gage 2 - Part II.

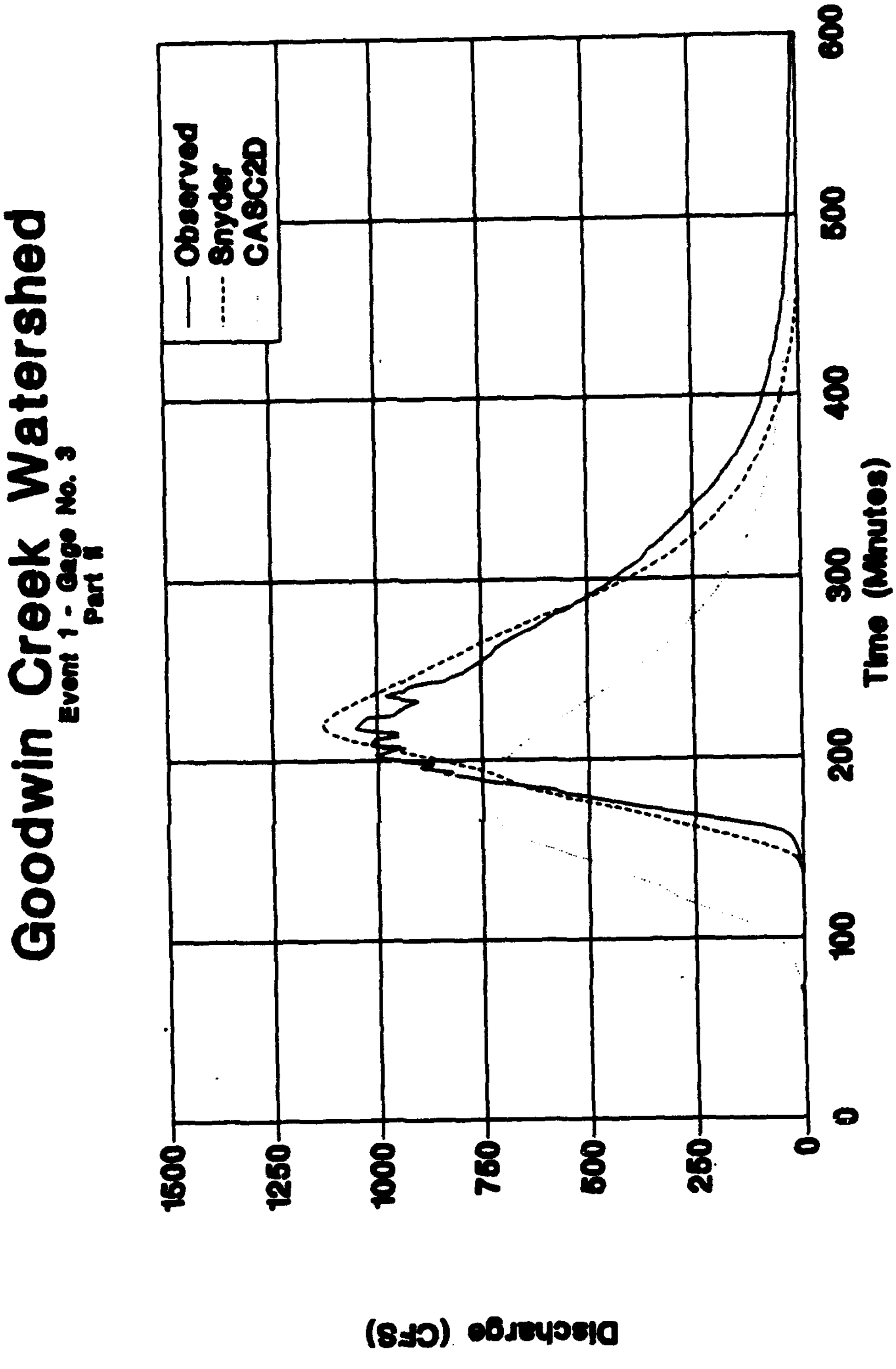

Figure B-3 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 1 at Gage 3 - Part II.

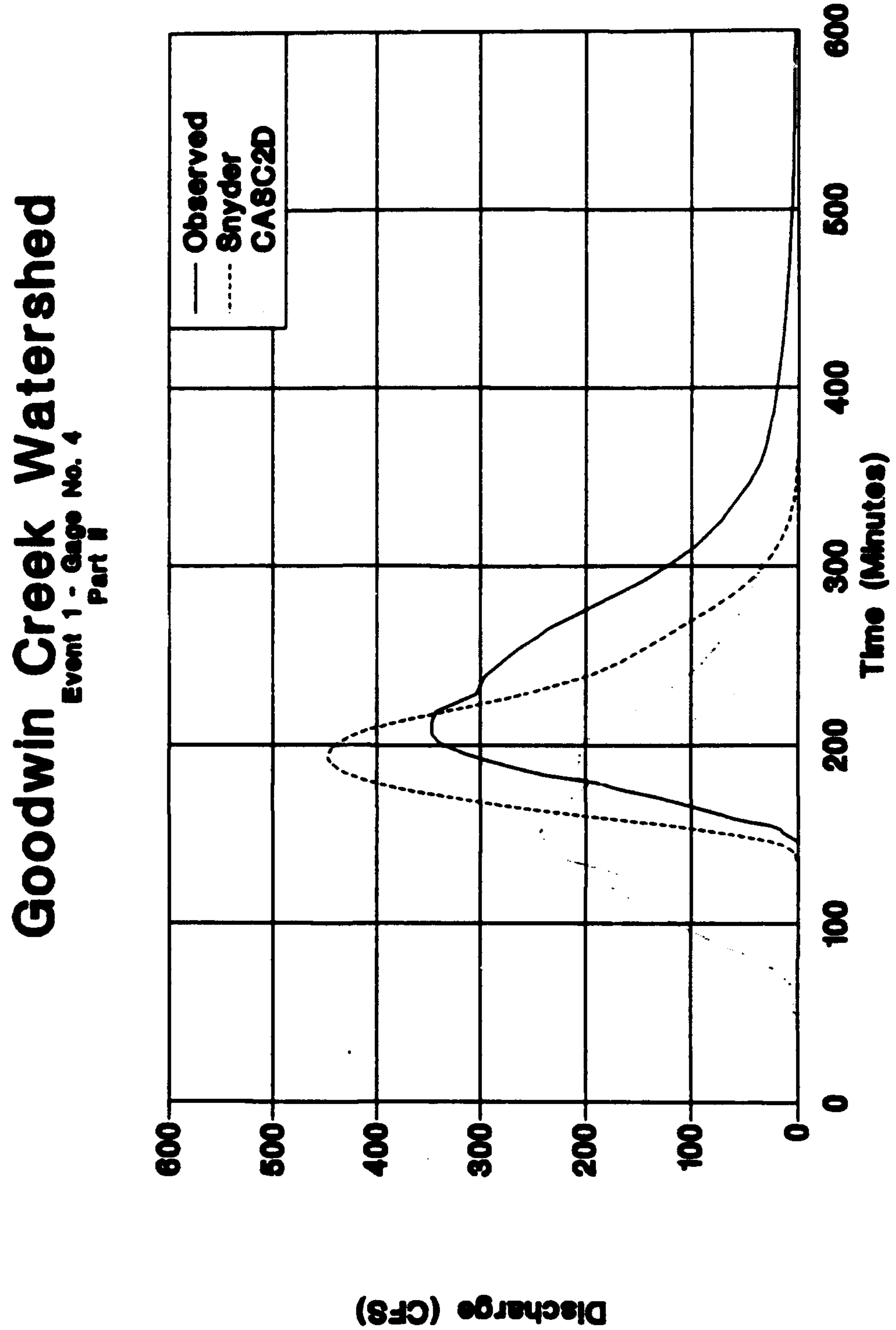

Figure B-4 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 1 at Gage 4 - Part II.

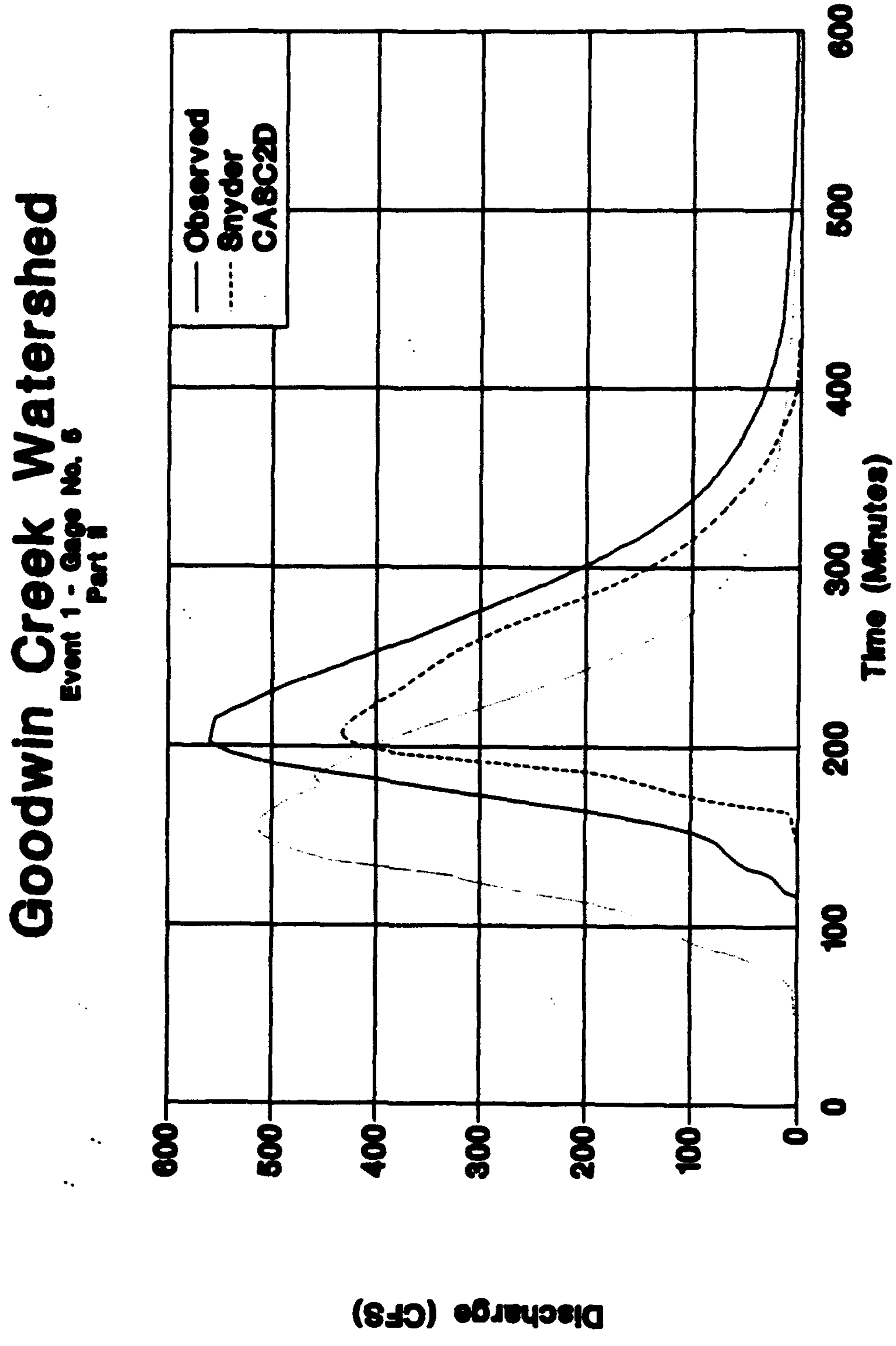

Figure B-5 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 1 at Gage 5 - Part II.

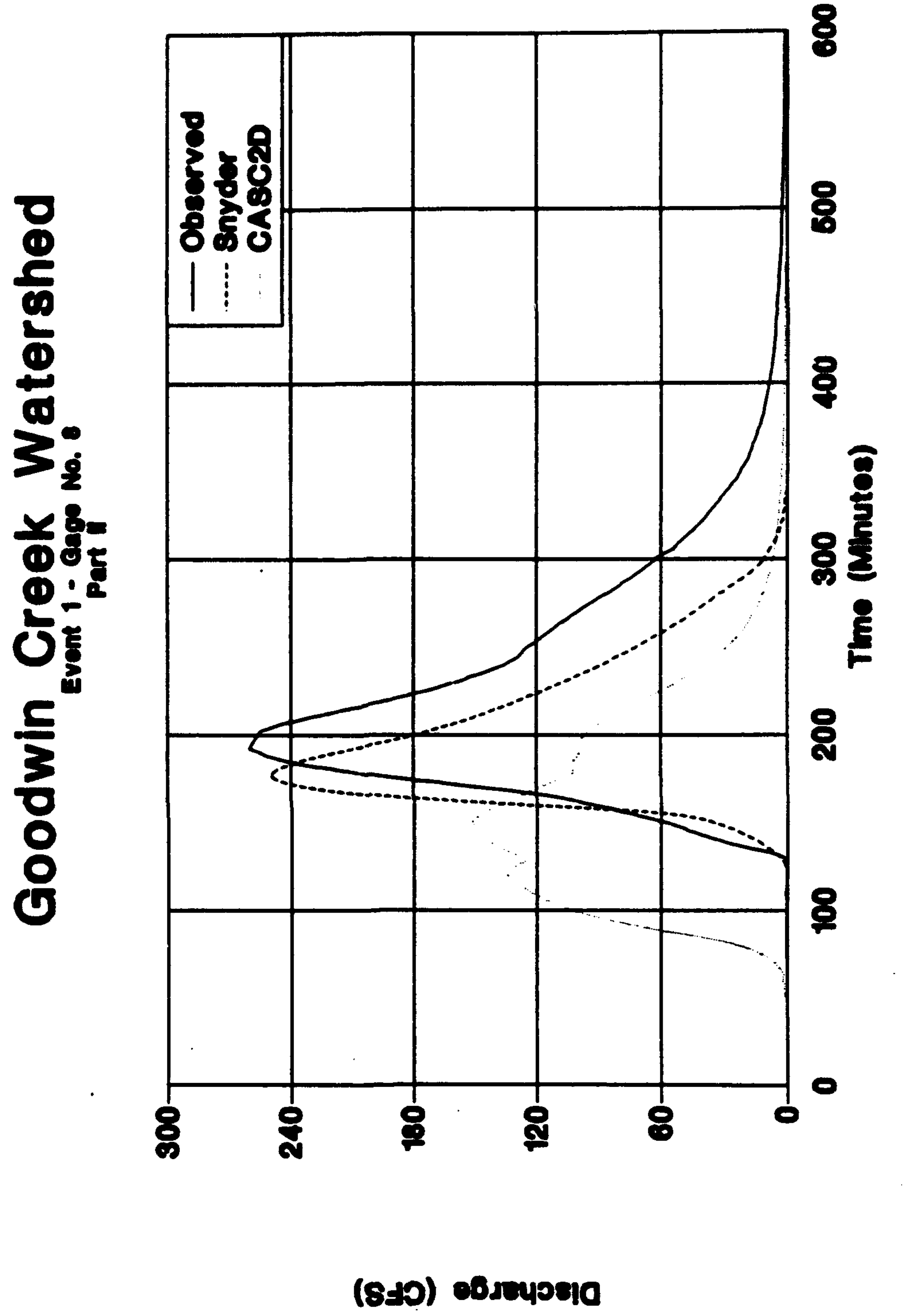

Figure B-6 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 1 at Gage 8 - Part II.

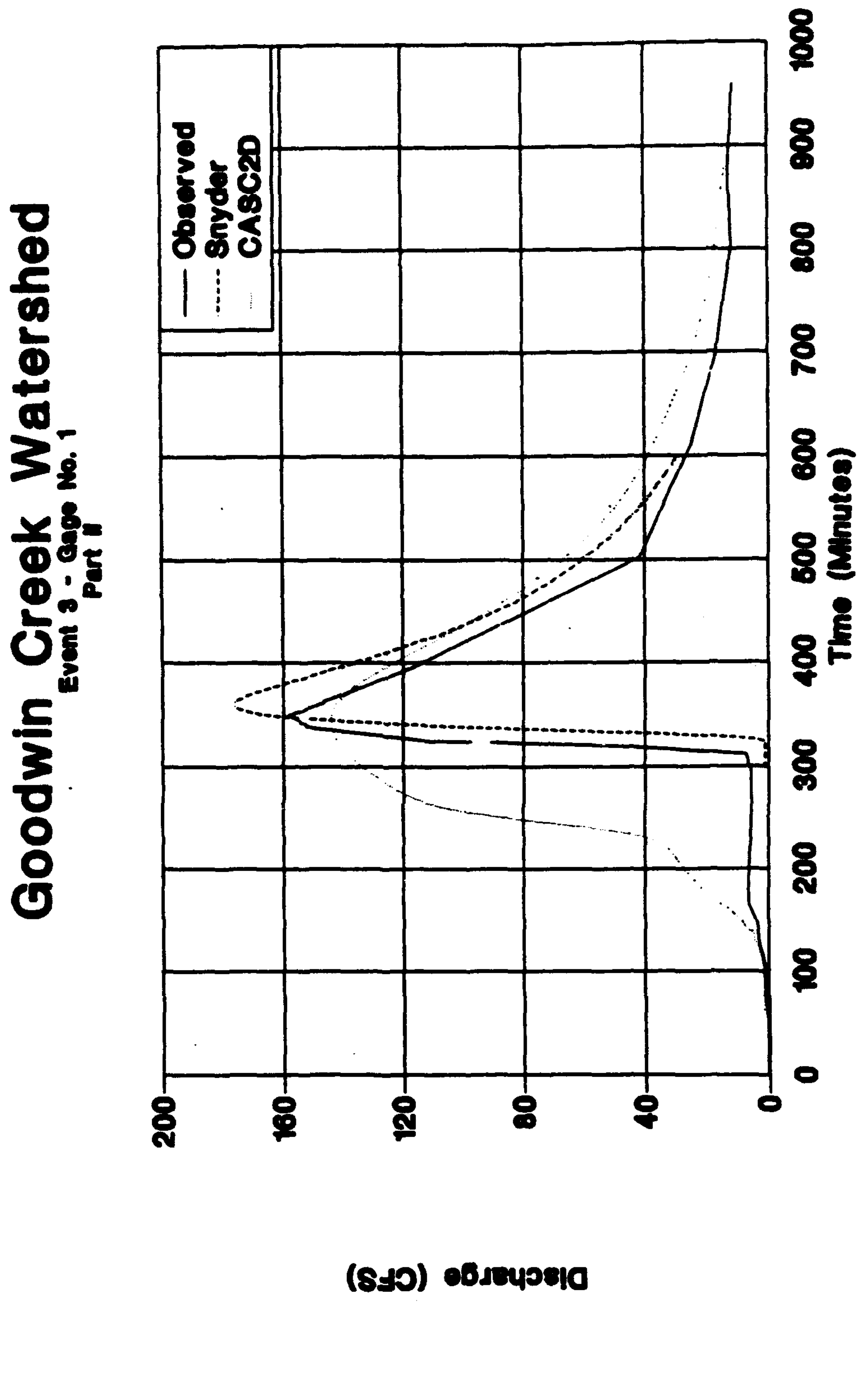

Figure B-7 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 3 at Gage 1 - Part II.

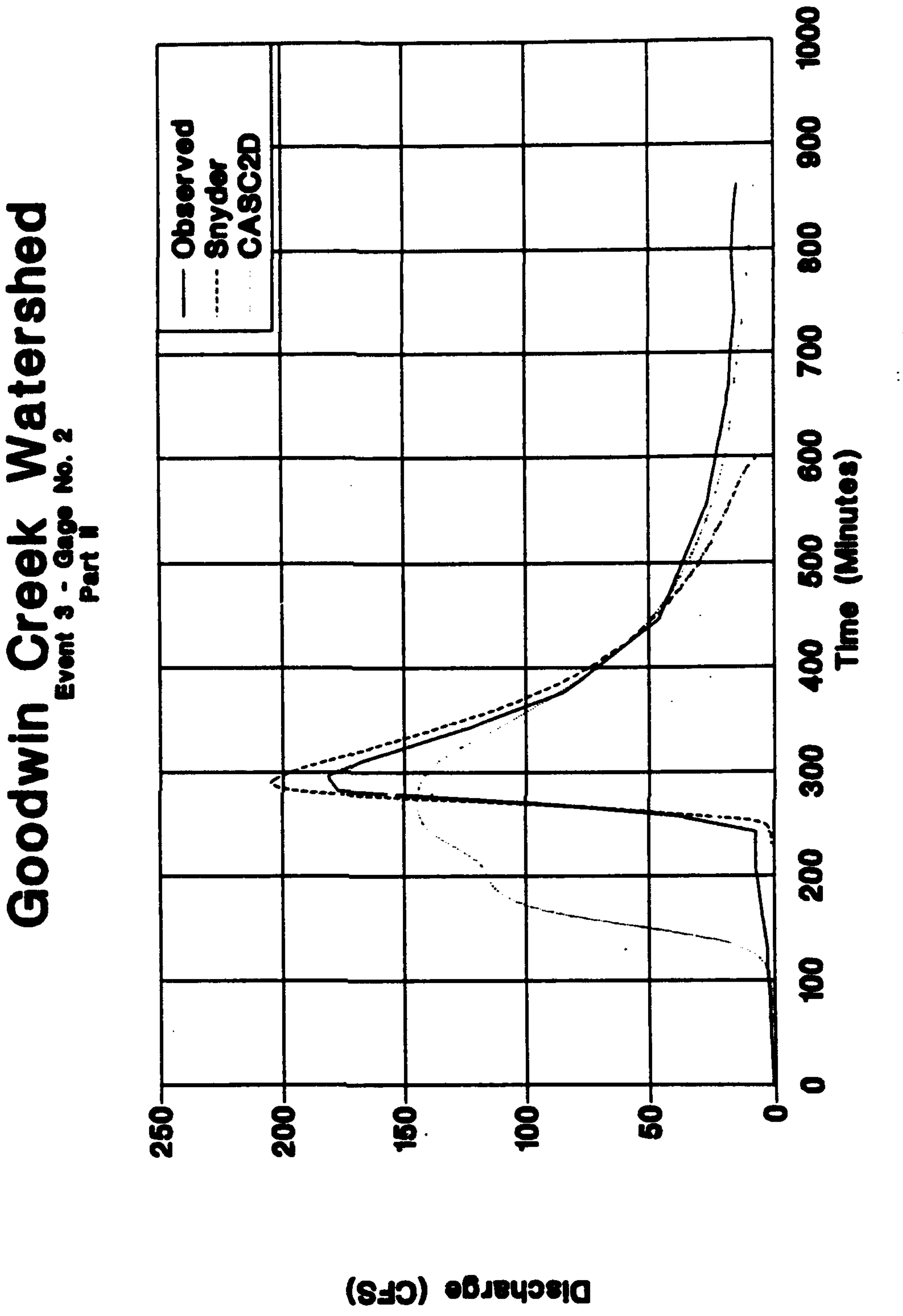

Figure B-8 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 3 at Gage 2 - Part II.

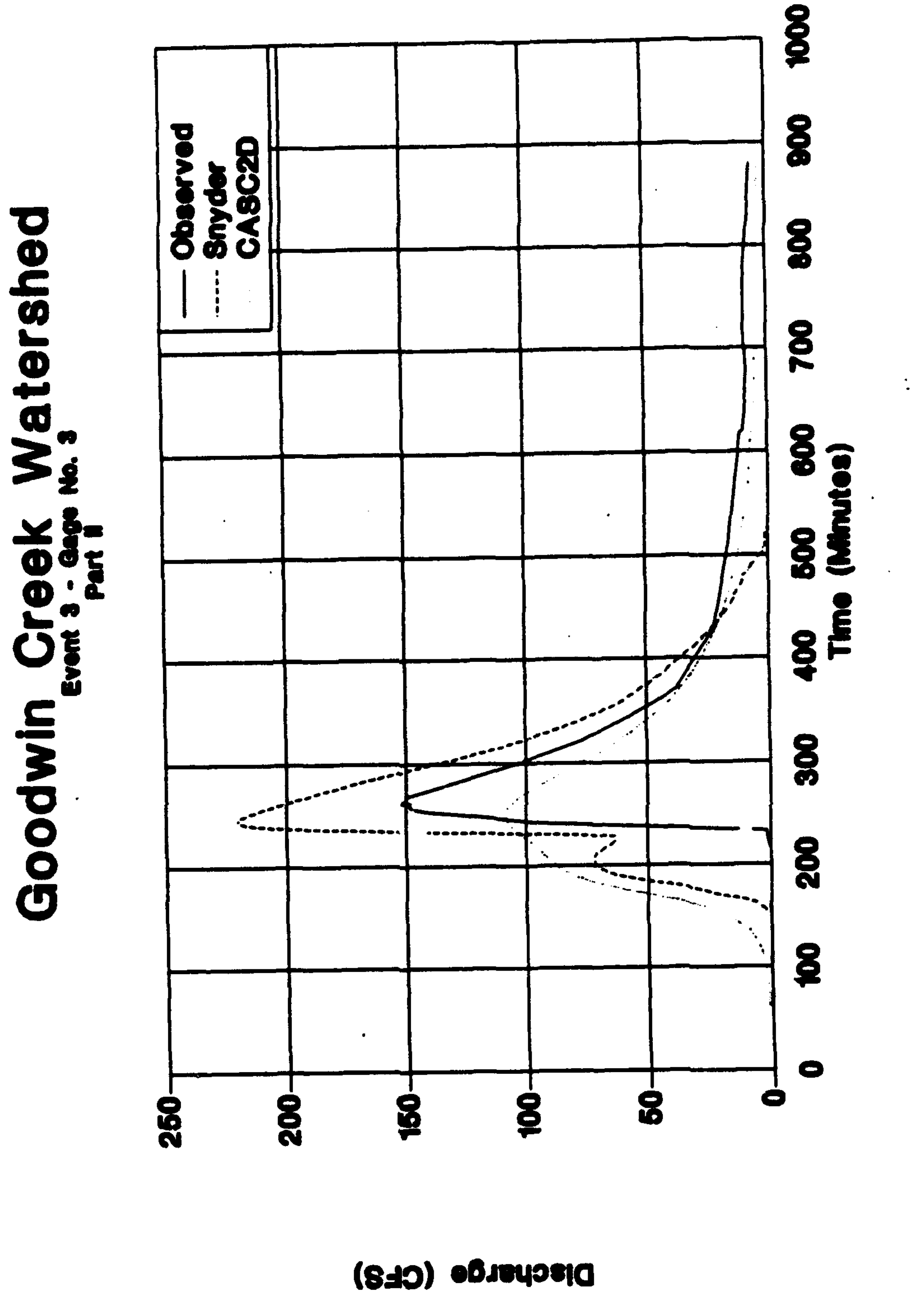

Figure B-9 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 3 at Gage 3 - Part II.

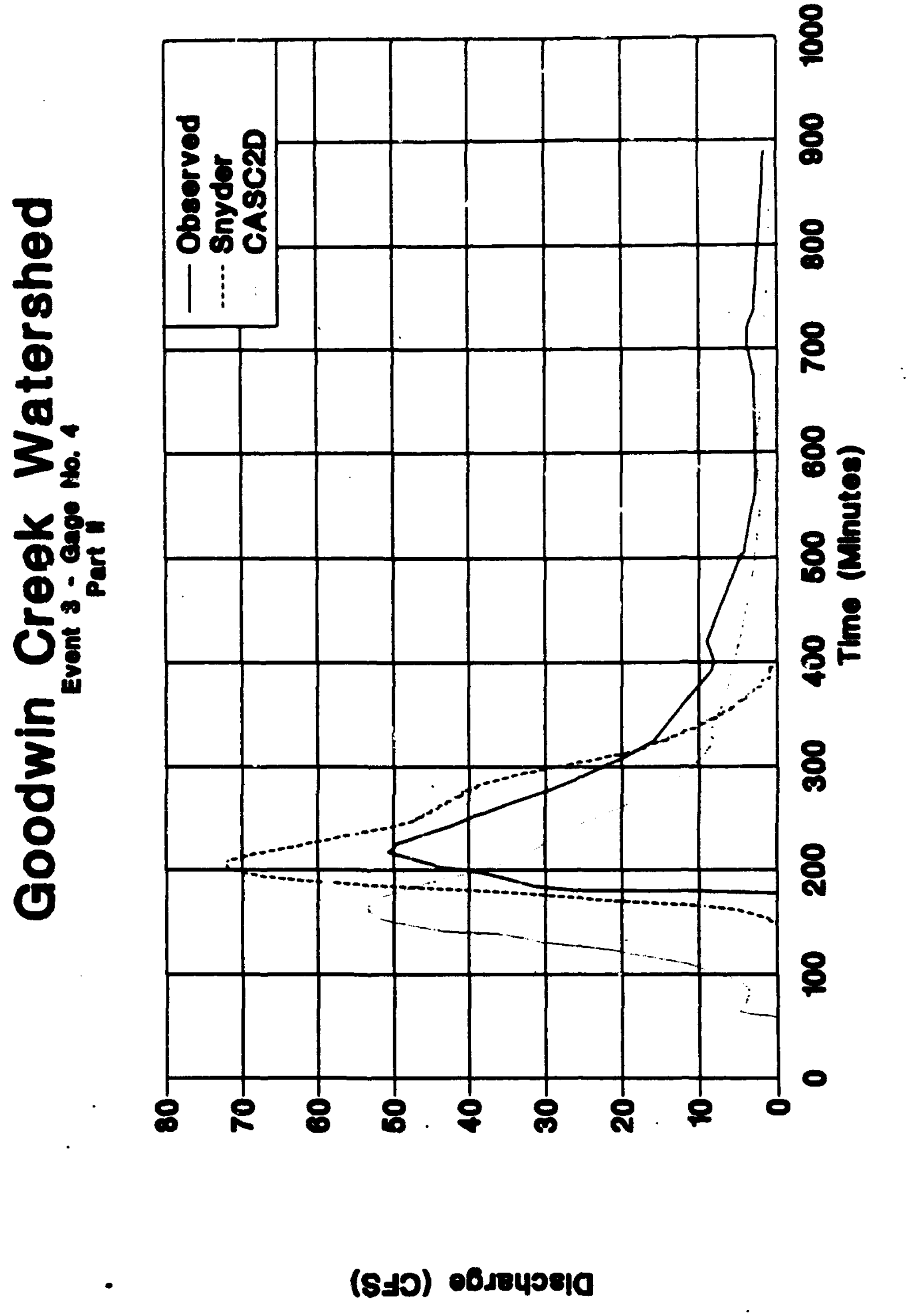

Figure B-10 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 3 at Gage 4 - Part II.

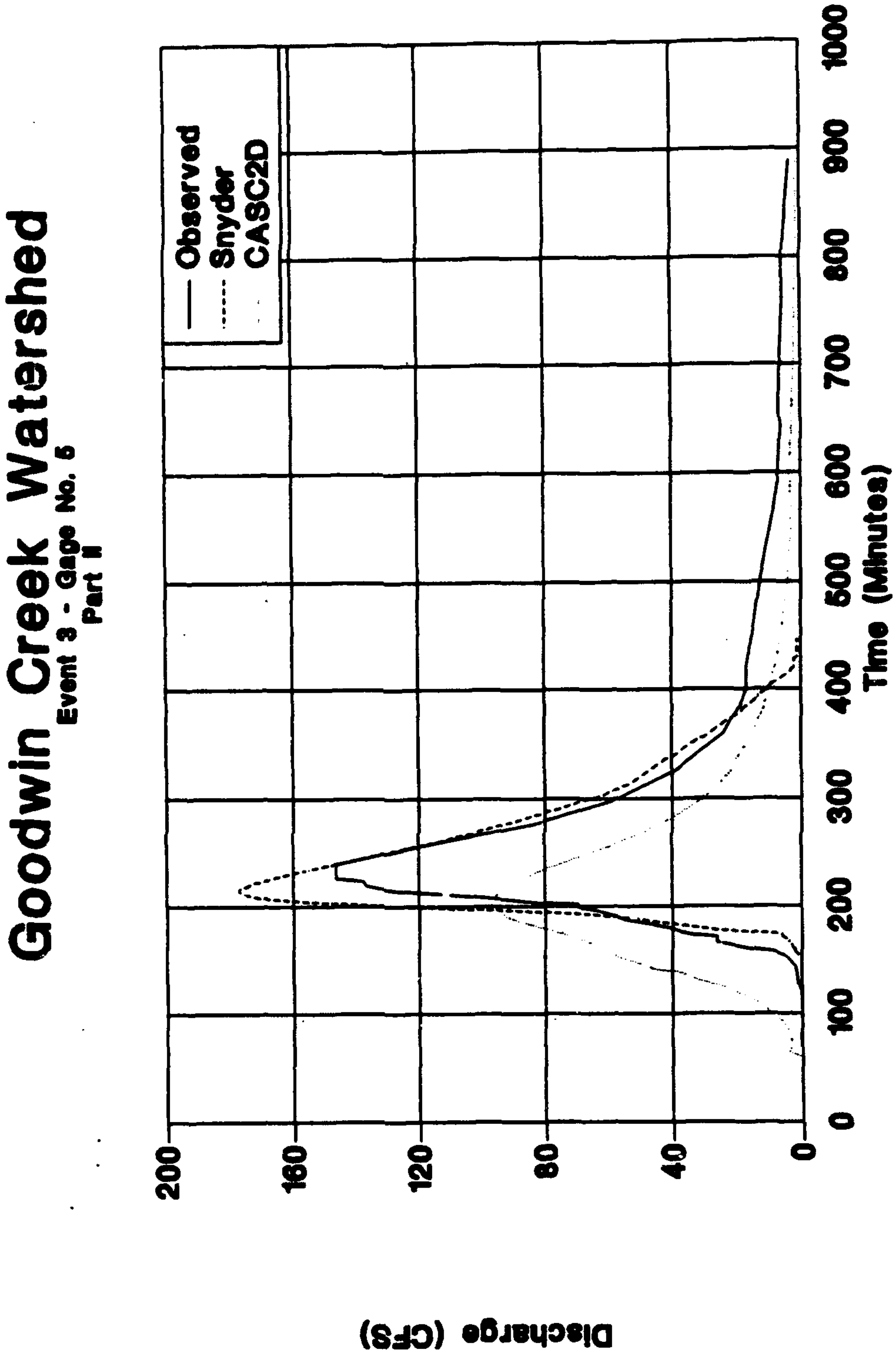

Figure B-11 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 3 at Gage 5 - Part II.

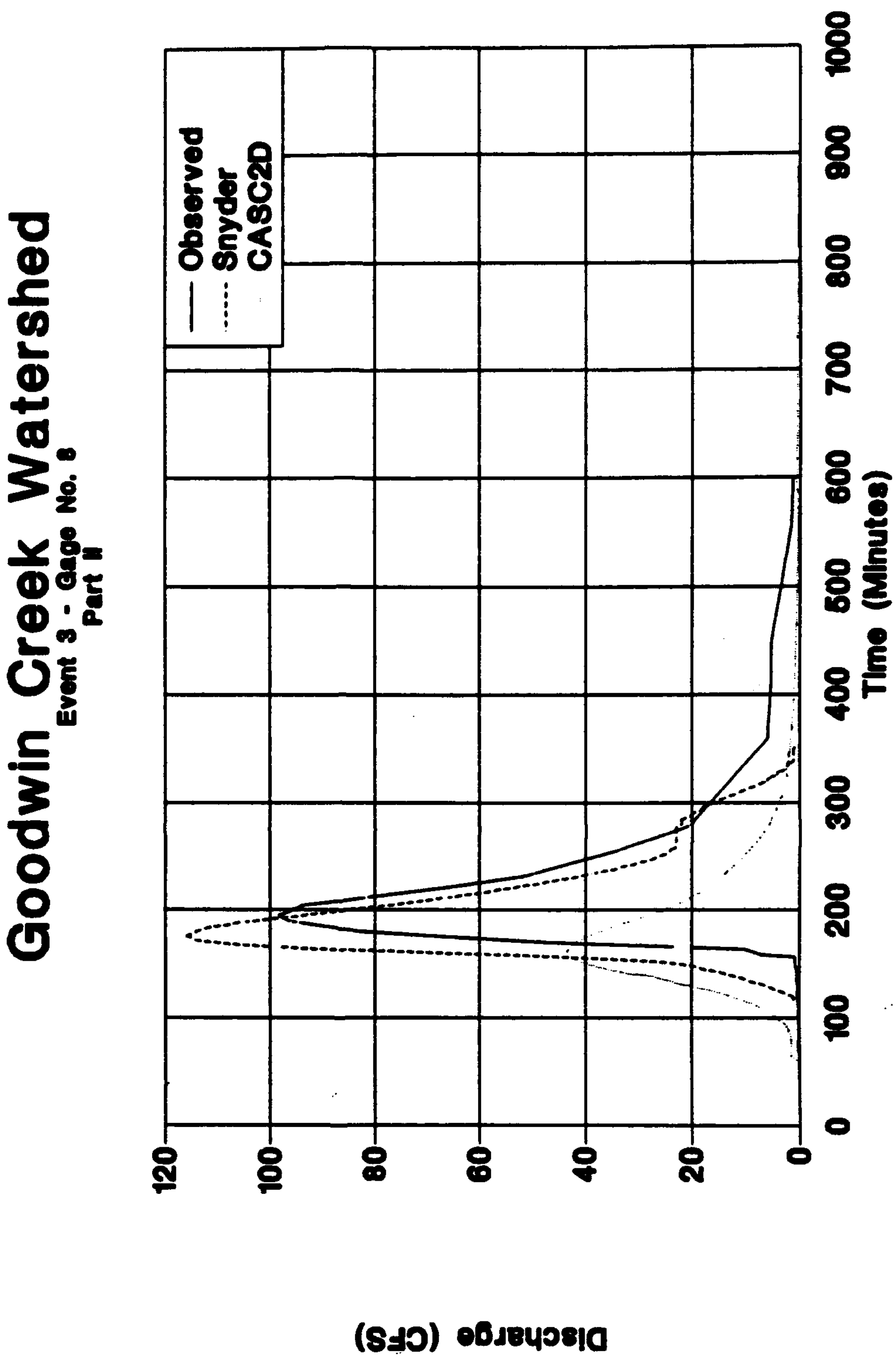

Figure B-12 - Plot of Computed Hydrographs versus Observed Hydrograph for Storm Event 3 at Gage 8 - Part II.

APPENDIX C - Sample Input Files

```
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IO
PG     4
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PI 0.007   0.007   0.007   0.007   0.007   0.020   0.020   0.020   0.020   0.020
PI 0.020   0.020   0.012   0.012   0.012   0.012   0.012   0.012   0.025   0.025
PI 0.025   0.025   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
PI 0.003
PG     6
IN     1 18OCT81    2119
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.008   0.008   0.008   0.008   0.008   0.008   0.008   0.008
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.027   0.027   0.027   0.027   0.027   0.027
PI 0.027   0.027   0.027   0.027   0.027   0.027   0.018   0.018   0.018   0.018
PI 0.018   0.018   0.018   0.018   0.018   0.018   0.018   0.018   0.018   0.018
PI 0.018   0.070   0.015   0.015   0.015   0.015   0.015   0.015   0.039   0.039
PI 0.039   0.039   0.039   0.039   0.039   0.039   0.039   0.039   0.005   0.005
PI 0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
```

Sample Input for Snyder Lumped Model

```
PI 0.031   0.031   0.031   0.031   0.031   0.031   0.031   0.031   0.031   0.031
PI 0.031   0.031   0.031   0.031   0.031   0.031   0.031   0.031   0.031   0.031
PI 0.031   0.031   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
PI 0.040   0.040   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
PI 0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.010   0.010   0.010   0.010
PI 0.010   0.010   0.010   0.010   0.010   0.010   0.010   0.010   0.020   0.020
PI 0.020   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
PI 0.005
PG     7
IN     1 18OCT81    2119
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.014   0.014   0.014   0.014   0.014   0.014   0.014   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
PI 0.008   0.008   0.008   0.008   0.008   0.008   0.008   0.008   0.008   0.008
PI 0.008   0.008   0.032   0.032   0.032   0.032   0.032   0.032   0.032   0.032
PI 0.032   0.046   0.046   0.046   0.046   0.046   0.046   0.046   0.003   0.003
PI 0.003   0.003   0.016   0.016   0.016   0.016   0.016   0.016   0.016   0.016
PI 0.016   0.016   0.016   0.016   0.016   0.011   0.011   0.011   0.011   0.011
PI 0.011   0.011   0.025   0.025   0.025   0.025   0.042   0.042   0.042   0.042
PI 0.042   0.042   0.042   0.042   0.042   0.042   0.042   0.045   0.045   0.045
PI 0.045   0.045   0.045   0.045   0.045   0.040   0.040   0.040   0.040   0.040
PI 0.060   0.080   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011
PI 0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.035   0.035   0.035
PI 0.035   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.000
PI 0.000
PG     8
IN     1 18OCT81    2119
PI 0.000   0.000   0.000   0.004   0.004   0.004   0.004   0.004   0.004   0.004
PI 0.004   0.004   0.004   0.004   0.004   0.004   0.004   0.004   0.004   0.007
PI 0.007   0.007   0.007   0.007   0.007   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.027   0.027   0.027   0.027   0.027
PI 0.027   0.018   0.018   0.018   0.018   0.018   0.018   0.018   0.018   0.018
PI 0.018   0.018   0.022   0.022   0.022   0.022   0.022   0.022   0.022   0.022
PI 0.022   0.023   0.023   0.023   0.023   0.023   0.023   0.023   0.023   0.023
PI 0.023   0.023   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
PI 0.040   0.005   0.005   0.005   0.005   0.005   0.005   0.018   0.018   0.018
PI 0.018   0.018   0.018   0.018   0.018   0.018   0.018   0.018   0.018   0.017
PI 0.017   0.017   0.017   0.017   0.017   0.017   0.017   0.017   0.017   0.017
PI 0.017   0.017   0.017   0.069   0.069   0.069   0.069   0.069   0.069   0.069
PI 0.069   0.069   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.025   0.025   0.020   0.020   0.005   0.005   0.005   0.005   0.005
PI 0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
PI 0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
PI 0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
PI 0.023   0.023   0.023   0.023   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.017   0.017
PI 0.017
PG    10
IN     1 18OCT81    2119
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.020   0.020   0.020   0.020   0.020   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
```

Sample input for Snyder Lumped Model - Continued

```
PI 0.000  0.000  0.000  0.000  0.031  0.031  0.031  0.031  0.031  0.031
PI 0.031  0.031  0.031  0.031  0.031  0.002  0.002  0.002  0.002  0.002
PI 0.035  0.035  0.035  0.035  0.010  0.010  0.010  0.010  0.010  0.010
PI 0.010  0.033  0.033  0.033  0.033  0.033  0.033  0.033  0.033  0.033
PI 0.033  0.033  0.033  0.033  0.033  0.033  0.033  0.033  0.033  0.033
PI 0.004  0.004  0.004  0.004  0.004  0.020  0.020  0.020  0.020  0.020
PI 0.020  0.020  0.020  0.020  0.020  0.020  0.020  0.030  0.030  0.030
PI 0.030  0.030  0.030  0.030  0.030  0.030  0.030  0.030  0.030  0.030
PI 0.030  0.030  0.030  0.030  0.030  0.030  0.030  0.030  0.030  0.030
PI 0.030  0.030  0.030  0.016  0.016  0.016  0.016  0.016  0.016  0.016
PI 0.016  0.000  0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006
PI 0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006
PI 0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006
PI 0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006
PI 0.006  0.019  0.019  0.019  0.019  0.019  0.019  0.019  0.019  0.019
PI 0.010  0.010  0.010  0.010  0.010  0.010  0.010  0.050  0.050  0.003
PI 0.003
PG    11
IN     1 18OCT81   2119
PI 0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000
PI 0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000
PI 0.000  0.000  0.000  0.005  0.005  0.030  0.030  0.030  0.001  0.001
PI 0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001
PI 0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001
PI 0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001
PI 0.001  0.001  0.001  0.001  0.001  0.017  0.017  0.017  0.050  0.050
PI 0.050  0.050  0.023  0.023  0.023  0.023  0.023  0.023  0.023  0.008
PI 0.008  0.008  0.008  0.008  0.050  0.050  0.013  0.013  0.013  0.010
PI 0.010  0.010  0.025  0.025  0.025  0.025  0.025  0.025  0.064  0.064
PI 0.064  0.064  0.064  0.026  0.026  0.026  0.026  0.026  0.007  0.007
PI 0.007  0.002  0.002  0.002  0.002  0.002  0.007  0.007  0.007  0.007
PI 0.007  0.007  0.042  0.042  0.042  0.042  0.042  0.011  0.011  0.011
PI 0.011  0.011  0.011  0.011  0.011  0.011  0.028  0.028  0.028  0.028
PI 0.028  0.045  0.045  0.045  0.045  0.080  0.080  0.037  0.037  0.037
PI 0.040  0.050  0.020  0.020  0.020  0.020  0.020  0.011  0.011  0.011
PI 0.011  0.011  0.011  0.011  0.006  0.006  0.006  0.006  0.006  0.006
PI 0.006  0.006  0.006  0.006  0.005  0.005  0.005  0.005  0.005  0.005
PI 0.005  0.005  0.005  0.005  0.005  0.005  0.005  0.005  0.005  0.006
PI 0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.080  0.012
PI 0.012  0.012  0.012  0.012  0.012  0.009  0.009  0.009  0.009  0.009
PI 0.009
PG    13
IN     1 18OCT81   2119
PI 0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000
PI 0.000  0.023  0.023  0.023  0.001  0.001  0.001  0.001  0.001  0.001
PI 0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001
PI 0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001
PI 0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001
PI 0.001  0.001  0.001  0.001  0.012  0.012  0.012  0.012  0.012  0.012
PI 0.012  0.012  0.012  0.012  0.003  0.003  0.003  0.003  0.003  0.003
PI 0.003  0.018  0.018  0.018  0.018  0.006  0.006  0.006  0.006  0.006
PI 0.034  0.034  0.034  0.034  0.034  0.034  0.034  0.034  0.034  0.034
PI 0.034  0.034  0.034  0.034  0.034  0.034  0.034  0.002  0.002  0.002
PI 0.002  0.002  0.015  0.015  0.018  0.018  0.018  0.018  0.018  0.018
PI 0.018  0.018  0.018  0.018  0.018  0.018  0.010  0.010  0.010  0.010
PI 0.010  0.010  0.010  0.010  0.041  0.041  0.041  0.041  0.041  0.041
PI 0.041  0.041  0.041  0.041  0.041  0.041  0.041  0.041  0.041  0.041
PI 0.041  0.041  0.041  0.018  0.018  0.018  0.018  0.018  0.018  0.018
PI 0.018  0.020  0.020  0.007  0.007  0.007  0.007  0.007  0.007  0.007
PI 0.007  0.007  0.007  0.007  0.007  0.007  0.007  0.006  0.006  0.006
PI 0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006
PI 0.006  0.006  0.006  0.006  0.006  0.013  0.013  0.013  0.013  0.013
PI 0.013  0.013  0.013  0.013  0.013  0.013  0.011  0.011  0.011  0.011
PI 0.011  0.011  0.011  0.011  0.011  0.004  0.004  0.004  0.004  0.004
PI 0.004
PG    14
```

Sample input for Snyder Lumped Model - Continued

```
IN      1 18OCT81     2119
PI 0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
PI 0.000    0.000    0.020    0.020    0.020    0.020    0.020    0.000    0.000    0.000
PI 0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
PI 0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
PI 0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
PI 0.000    0.000    0.000    0.000    0.000    0.000    0.033    0.033    0.033    0.013
PI 0.013    0.013    0.013    0.013    0.013    0.001    0.001    0.001    0.001    0.001
PI 0.001    0.001    0.010    0.010    0.010    0.010    0.010    0.010    0.010    0.010
PI 0.036    0.036    0.036    0.036    0.036    0.036    0.036    0.036    0.036    0.036
PI 0.036    0.036    0.036    0.036    0.036    0.036    0.036    0.036    0.003    0.003
PI 0.003    0.003    0.003    0.003    0.008    0.008    0.008    0.008    0.008    0.008
PI 0.028    0.028    0.028    0.028    0.028    0.028    0.032    0.032    0.032    0.032
PI 0.032    0.032    0.032    0.032    0.032    0.032    0.032    0.032    0.032    0.032
PI 0.032    0.032    0.032    0.032    0.032    0.037    0.037    0.037    0.037    0.037
PI 0.037    0.037    0.037    0.037    0.014    0.014    0.014    0.014    0.014    0.014
PI 0.014    0.010    0.009    0.009    0.009    0.009    0.009    0.009    0.009    0.009
PI 0.009    0.009    0.009    0.009    0.009    0.009    0.005    0.005    0.005    0.005
PI 0.005    0.005    0.005    0.005    0.005    0.005    0.005    0.005    0.005    0.005
PI 0.005    0.005    0.005    0.005    0.005    0.005    0.005    0.013    0.013    0.013
PI 0.013    0.013    0.013    0.013    0.013    0.013    0.013    0.013    0.013    0.013
PI 0.013    0.013    0.013    0.013    0.013    0.003    0.003    0.003    0.003    0.003
PI 0.003
PI 0.171
PG     50
IN      1 18OCT81     2119
PI 0.000    0.004    0.004    0.004    0.004    0.004    0.004    0.040    0.040    0.001
PI 0.001    0.001    0.001    0.001    0.001    0.001    0.001    0.001    0.001    0.001
PI 0.001    0.001    0.001    0.001    0.001    0.001    0.001    0.001    0.001    0.001
PI 0.001    0.001    0.001    0.001    0.001    0.001    0.001    0.001    0.001    0.001
PI 0.001    0.001    0.001    0.001    0.001    0.001    0.001    0.020    0.020    0.020
PI 0.020    0.020    0.020    0.020    0.020    0.020    0.020    0.003    0.003    0.003
PI 0.003    0.003    0.003    0.003    0.020    0.020    0.020    0.020    0.027    0.027
PI 0.027    0.027    0.027    0.027    0.027    0.027    0.027    0.027    0.027    0.027
PI 0.027    0.027    0.027    0.027    0.027    0.027    0.027    0.027    0.027    0.027
PI 0.027    0.027    0.027    0.027    0.000    0.000    0.000    0.025    0.025    0.015
PI 0.015    0.015    0.015    0.015    0.015    0.015    0.015    0.015    0.015    0.015
PI 0.015    0.015    0.015    0.015    0.024    0.024    0.024    0.024    0.024    0.024
PI 0.024    0.024    0.024    0.024    0.051    0.051    0.051    0.051    0.051    0.051
PI 0.051    0.051    0.043    0.043    0.043    0.043    0.043    0.043    0.043    0.013
PI 0.013    0.013    0.013    0.013    0.013    0.013    0.013    0.013    0.013    0.013
PI 0.080    0.002    0.002    0.002    0.002    0.002    0.002    0.002    0.002    0.002
PI 0.002    0.002    0.006    0.006    0.006    0.006    0.006    0.006    0.006    0.006
PI 0.006    0.006    0.006    0.006    0.006    0.006    0.006    0.006    0.006    0.006
PI 0.006    0.006    0.006    0.017    0.017    0.017    0.017    0.017    0.017    0.017
PI 0.010    0.010    0.010    0.010    0.010    0.010    0.010    0.010    0.010    0.020
PI 0.020    0.020    0.005    0.005    0.005    0.005    0.005    0.005    0.005    0.005
PI 0.005
PG     51
IN      1 18OCT81     2119
PI 0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
PI 0.000    0.000    0.018    0.018    0.018    0.018    0.006    0.006    0.006    0.006
PI 0.006    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
PI 0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
PI 0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
PI 0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.017    0.017    0.017
PI 0.008    0.008    0.008    0.008    0.008    0.008    0.002    0.002    0.002    0.002
PI 0.002    0.002    0.030    0.030    0.007    0.007    0.007    0.011    0.011    0.011
PI 0.011    0.011    0.011    0.011    0.036    0.036    0.036    0.036    0.036    0.036
PI 0.036    0.057    0.057    0.057    0.035    0.035    0.033    0.033    0.033    0.003
PI 0.003    0.003    0.003    0.003    0.003    0.003    0.040    0.005    0.005    0.005
PI 0.005    0.024    0.024    0.024    0.024    0.024    0.023    0.023    0.023    0.010
PI 0.010    0.010    0.010    0.010    0.010    0.028    0.028    0.028    0.028    0.028
PI 0.033    0.033    0.033    0.033    0.033    0.033    0.103    0.103    0.103    0.033
PI 0.033    0.033    0.033    0.030    0.030    0.030    0.030    0.030    0.030    0.030
PI 0.000    0.000    0.013    0.013    0.013    0.013    0.013    0.013    0.013    0.015
```

Sample input for Snyder Lumped Model - Continued

```
PI 0.015   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.010   0.010   0.010   0.025   0.025   0.008   0.008   0.008   0.008
PI 0.008   0.008   0.023   0.023   0.023   0.003   0.003   0.003   0.003   0.003
PI 0.003
PG    52
IN     1 18OCT81    2119
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.017   0.017   0.017   0.017   0.017   0.017   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.016   0.016   0.016   0.016
PI 0.016   0.013   0.013   0.013   0.004   0.004   0.004   0.004   0.004   0.004
PI 0.004   0.005   0.005   0.005   0.005   0.015   0.015   0.015   0.015   0.015
PI 0.015   0.015   0.015   0.048   0.048   0.048   0.048   0.048   0.048   0.048
PI 0.048   0.020   0.020   0.020   0.020   0.020   0.020   0.020   0.020   0.020
PI 0.000   0.000   0.000   0.017   0.017   0.017   0.003   0.003   0.003   0.003
PI 0.032   0.032   0.032   0.032   0.032   0.032   0.009   0.009   0.009   0.009
PI 0.009   0.009   0.009   0.009   0.025   0.025   0.025   0.025   0.025   0.025
PI 0.054   0.054   0.054   0.054   0.054   0.054   0.054   0.054   0.054   0.054
PI 0.054   0.035   0.035   0.035   0.035   0.017   0.017   0.017   0.017   0.017
PI 0.017   0.000   0.012   0.012   0.012   0.012   0.012   0.012   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.011
PI 0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.010
PI 0.010   0.020   0.020   0.020   0.020   0.002   0.002   0.002   0.002   0.002
PI 0.002
PG    53
IN     1 18OCT81    2119
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.007   0.007   0.007   0.007   0.007
PI 0.007   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002
PI 0.002   0.014   0.014   0.014   0.014   0.014   0.014   0.014   0.003   0.003
PI 0.003   0.017   0.017   0.017   0.017   0.017   0.017   0.017   0.018   0.018
PI 0.018   0.018   0.018   0.018   0.027   0.027   0.027   0.027   0.027   0.027
PI 0.027   0.045   0.045   0.033   0.033   0.033   0.033   0.035   0.035   0.035
PI 0.035   0.002   0.002   0.002   0.002   0.002   0.002   0.010   0.010   0.010
PI 0.003   0.003   0.003   0.012   0.012   0.012   0.012   0.012   0.120   0.011
PI 0.011   0.011   0.011   0.011   0.011   0.011   0.017   0.017   0.017   0.017
PI 0.017   0.017   0.050   0.050   0.010   0.010   0.067   0.067   0.067   0.050
PI 0.050   0.050   0.050   0.033   0.033   0.033   0.023   0.023   0.023   0.025
PI 0.025   0.007   0.007   0.007   0.007   0.007   0.007   0.007   0.007   0.007
PI 0.007   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
PI 0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.008   0.008   0.008   0.008   0.008   0.008   0.020   0.020   0.020
PI 0.005   0.005   0.005   0.005   0.005   0.005   0.018   0.018   0.018   0.018
PI 0.003
PG    54
IN     1 18OCT81    2119
PI 0.000   0.000   0.016   0.016   0.016   0.016   0.016   0.016   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.053   0.053
PI 0.053   0.014   0.014   0.014   0.014   0.014   0.014   0.014   0.006   0.006
PI 0.006   0.006   0.006   0.027   0.027   0.027   0.028   0.028   0.028   0.028
PI 0.028   0.028   0.028   0.028   0.028   0.028   0.028   0.028   0.028   0.028
PI 0.028   0.028   0.030   0.030   0.030   0.030   0.030   0.030   0.007   0.007
PI 0.007   0.007   0.007   0.007   0.007   0.012   0.012   0.012   0.012   0.012
```

Sample input for Snyder Lumped Model - Continued

```
PI 0.012   0.018   0.018   0.018   0.018   0.018   0.018   0.016   0.016   0.016
PI 0.016   0.016   0.016   0.016   0.016   0.016   0.016   0.016   0.016   0.016
PI 0.016   0.050   0.050   0.050   0.050   0.050   0.050   0.050   0.050   0.035
PI 0.035   0.035   0.035   0.035   0.035   0.035   0.035   0.011   0.011   0.011
PI 0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011
PI 0.011   0.000   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.026
PI 0.026   0.026   0.026   0.026   0.007   0.007   0.007   0.007   0.007   0.007
PI 0.007   0.007   0.007   0.007   0.015   0.015   0.015   0.015   0.002   0.002
PI 0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002
PI 0.002
PG    55
IN     1 18OCT81    2119
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.020   0.020   0.020   0.020   0.020   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.024   0.024   0.024
PI 0.024   0.024   0.024   0.024   0.024   0.024   0.024   0.024   0.024   0.024
PI 0.003   0.003   0.003   0.003   0.032   0.032   0.032   0.032   0.032   0.007
PI 0.007   0.007   0.024   0.024   0.024   0.024   0.024   0.024   0.024   0.024
PI 0.024   0.024   0.024   0.024   0.024   0.024   0.036   0.036   0.036   0.036
PI 0.036   0.036   0.036   0.036   0.004   0.004   0.004   0.004   0.004   0.004
PI 0.004   0.015   0.015   0.005   0.005   0.021   0.021   0.021   0.021   0.021
PI 0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021
PI 0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021
PI 0.021   0.049   0.049   0.049   0.049   0.049   0.049   0.049   0.090   0.090
PI 0.090   0.000   0.040   0.040   0.040   0.040   0.040   0.040   0.009   0.009
PI 0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009
PI 0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.007   0.007   0.007
PI 0.007   0.007   0.007   0.007   0.007   0.007   0.007   0.007   0.007   0.007
PI 0.007   0.007   0.007   0.007   0.007   0.009   0.009   0.009   0.009   0.009
PI 0.009   0.009   0.009   0.009   0.002   0.002   0.002   0.002   0.002   0.001
PI 0.001
KK  SA14
KM Runoff for Sub-Area 14
BA  0.14
PR    11
PW     1
LG  1.20     .13    6.57   .1983
US  0.51   0.843
KK 18-17
KM Routing from node 18 to node 17
RD
RC   .08     .04     .08    2075  .00410
RX  4949    4950    4975    4996    5004    5025    5030    5050
RY 343.0   342.0   337.0   327.0   327.0   337.0   342.0   342.0
KK  SA13
BA  0.31
PR     8      11
PW  .299    .701
LG  1.20     .13    6.57   .1983
US  0.99   0.843
KK  C171
KM Combine Hydrographs at node 17
HC     2
KK 17-15
KM Routing from node 17 to node 15
RD
RC   .08     .04     .08    2075  .00386
RX  4949    4950    4975    4996    5004    5025    5030    5050
RY 343.0   342.0   337.0   327.0   327.0   337.0   342.0   342.0
KK  SA11
```

Sample input for Snyder Lumped Model - Continued

```
KM Runoff for Sub-Area 11
BA  0.17
PR    10      11
PW  .262    .737
LG  1.20     .13    6.57   .1983
US  0.63   0.843
KK 16-15
KM Routing from node 16 to node 15
RD
RC   .08     .04     .08    2500  .00400
RX  4949    4950    4975    4996    5004    5025    5030    5050
RY 343.0   342.0   337.0   327.0   327.0   337.0   342.0   342.0
KK  SA12
KM Runoff for Sub-Area 12
BA  0.07
PR     8
PW     1
LG  1.20     .13    6.57   .1983
US  0.58   0.843
KK  C151
KM Combine Hydrographs at node 15
HC     3
KK GAGE8
KM Observed vs. Computed
IN     2 18OCT81    2119
QO   0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO   0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO   0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO   0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.1     0.1     0.1
QO   0.1     0.1     0.1     0.1     0.1     0.1     0.1     0.1     0.1     0.1
QO   0.1     0.1     0.1     0.1     0.2     0.2     0.2     0.1     0.1     0.1
QO   0.1     0.1     0.1     0.1     0.3     1.8     6.2    12.7    20.3    27.7
QO  33.1    38.5    43.8    48.2    53.4    59.0    65.0    72.0    79.5    84.7
QO  92.8   100.4   108.5   120.4   132.7   148.3   163.7   178.4   192.5   205.7
QO 216.3   228.8   238.5   245.1   251.7   255.1   260.2   259.1   258.1   257.1
QO 256.1   255.1   250.0   245.0   236.8   230.4   221.7   214.8   205.7   199.7
QO 191.0   183.9   177.0   170.2   164.9   158.4   153.9   148.3   143.4   139.8
QO 135.0   132.7   129.2   127.7   126.2   124.7   121.4   119.2   117.0   114.9
QO 112.7   110.6   108.5   105.4   103.4   100.4    98.5    95.7    92.9    90.1
QO  87.4    84.3    81.6    79.5    77.0    74.1    71.6    69.3    66.9    64.6
QO  62.7    60.5    57.6    54.1    52.8    51.1    49.2    47.3    45.4    43.5
QO  41.7    40.0    38.5    37.4    36.0    34.4    32.8    31.6
 30.3    28.9
QO  27.4    26.3    24.9    23.6    22.8    21.9    20.9    19.9    19.0    18.2
QO  17.7    17.0    16.5    15.9    15.2    14.6    14.1    13.6    13.0    12.6
QO  12.1    11.5    11.1    10.8    10.5    10.2     9.8     9.5     9.2     9.0
QO   8.7     8.4     8.1     7.8     7.6     7.4     7.1     6.9     6.7     6.5
QO   6.3     6.2     6.1     5.9     5.8     5.6     5.5     5.3     5.2     5.1
QO   5.0     4.8     4.7     4.5     4.4     4.3     4.2     4.1     4.0     3.9
QO   3.8     3.8     3.7     3.6     3.5     3.3     3.2     3.1     3.1     3.0
QO   2.9     2.9     2.8     2.7     2.7     2.6     2.6     2.5     2.5     2.4
QO   2.4     2.3     2.3     2.2     2.2     2.1     2.1     2.1     2.0     2.0
QO   2.0     1.9     1.9     1.9     1.8     1.8     1.8     1.7     1.7     1.7
QO   1.6     1.6     1.5     1.5     1.5     1.4     1.4     1.4     1.4     1.3
QO   1.3     1.3     1.3     1.3     1.2     1.2     1.2     1.2     1.2     1.2
QO   1.1     1.1     1.1     1.1     1.1     1.1     1.0     1.0     1.0     1.0
KK 15-14
KM Routing from node 15 to node 14
RD
RC   .08     .04     .08    3800  .00513
RX  4848    4948    4954    4968    5031    5046    5098    5148
RY 338.5   336.5   337.0   329.0   320.5   335.0   336.5   336.5
KK   SA9
KM Runoff for Sub-Area 9
BA  0.86
PR     5      55      10       8
```

Sample input for Snyder Lumped Model - Continued

```
PW  .258    .242    .123    .377
LG  1.20     .13    6.57   .1983
US  1.47   0.843
KK  C141
KM Combine Hydrographs at node 14
HC     2
KK 14-12
KM Routing from node 14 to node 12
RD
RC   .08     .04     .08    3800  .00342
RX  4848    4948    4954    4968    5031    5046    5098    5148
RY 338.5   336.5   337.0   329.0   320.5   335.0   336.5   336.5
KK  SA10
KM Runoff for Sub-Area 10
BA  0.15
PR    10      11
PW  .949    .051
LG  1.20     .13    6.57   .1983
US  0.57   0.843
KK 13-12
KM Routing from node 13 to node 12
RD
RC  .100    .040    .100    5500  .00791
RX    20      70     120     127     144     160     220     270
RY 331.0   329.2   328.5   319.8   314.0   329.5   329.6   330.5
KK  C121
KM Combine hydrographs at node 12
HC     2
KK GAGES
KM Observed vs. Computed
IN     2 18OCT81    2119
QO   0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO   0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO   0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO   0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO   0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO   0.0     0.0     0.0     0.0     0.1     0.1     0.1     0.1     0.1     3.9
QO  12.3    15.6    18.5    21.4    25.4    32.9    42.8    50.8    57.1    61.6
QO  64.8    68.8    71.3    75.5    80.8    88.3    95.9   108.4   122.7   138.9
QO 158.1   176.9   198.7   220.1   244.8   270.6   292.7   313.3   337.0   357.6
QO 380.9   400.7   425.5   448.9   473.0   495.4   513.1   527.3   539.0   547.0
QO 554.9   560.3   559.5   558.6   557.8   557.0   556.1   555.3   550.9   544.3
QO 537.7   528.5   520.8   515.6   508.0   500.5   492.9   485.3   475.5   465.8
QO 456.1   448.9   438.3   429.0   421.0   409.7   400.9   392.1   383.3   374.5
QO 363.9   355.5   348.2   340.1   331.1   323.2   315.4   307.5   298.1   290.7
QO 283.3   276.0   267.0   258.3   251.4   242.9   234.7   228.1   220.1   213.8
QO 204.6   198.6   191.2   185.4   178.3   172.8   167.2   160.5   152.7   147.6
QO 141.4   136.6   131.9   127.1   122.4   116.8   112.6   108.4   104.2   100.0
QO  95.9    92.0    89.1    85.4    82.6    79.9    76.4    74.7    72.1    69.2
QO  66.8    64.8    62.8    60.5    58.3    56.4    54.6    52.8    51.1    49.3
QO  47.7    45.7    44.1    42.5    41.0    39.5    37.7    36.2    35.1    34.0
QO  32.6    31.3    30.0    28.8    27.8    27.1    26.1    24.9    24.0    23.1
QO  22.5    21.8    21.0    20.1    19.6    19.1    18.5    17.8    17.2    16.7
QO  16.3    15.9    15.6    15.2    14.9    14.6    14.2    13.9    13.7    13.4
QO  13.2    13.0    12.8    12.5    12.3    12.1    11.9    11.8    11.5    11.2
QO  10.9    10.7    10.5    10.4    10.2    10.0     9.8     9.5     9.3     9.2
QO   9.0     8.9     8.7     8.6     8.4     8.2     8.1     8.0     7.8     7.7
QO   7.5     7.4     7.3     7.1     7.0     6.9     6.8     6.6     6.5     6.3
QO   6.2     6.1     6.0     5.9     5.8     5.7     5.7     5.6     5.5     5.4
QO   5.3     5.2     5.1     5.0     5.0     4.9     4.8     4.8     4.7     4.7
QO   4.6     4.6     4.5     4.4     4.4     4.3     4.2     4.1     4.0     3.9
KK 12-10
KM Routing from node 12 to node 10
RD
RC  .070    .038    .070    3500  .00443
RX    20     120     126     139     165     172     208     248
```

Sample input for Snyder Lumped Model - Continued

```
RY 279.8   280.5   276.0   268.0   270.5   274.0   280.5  280.2
KK   SA8
KM Runoff from Sub-Area 8
BA  0.46
PR     6       5       8
PW  .702    .072    .226
LG  1.20     .13    6.57   .1983
US  1.05   0.843
KK 11-10
KM Routing from node 11 to node 10
RD
RC   .07    .038     .07    2850  .00542
RX    20     120     126     139     165     172     208     248
RY 279.8   280.5   276.0   268.0   270.5   274.0   280.5   280.2
KK   SA6
KM Runoff from Sub-Area 6
BA  1.29
PR     6       4      54       7      55       5
PW  .601    .090    .128    .012    .061    .108
LG  1.20     .13    6.57   .1983
US  1.54   0.843
KK  C101
KM Combine Hydrographs at node 10
HC     3
KK  10-7
KM Routing from node 10 to node 7
RD
RC  .070    .038    .070    3650  .00315
RX    20     120     126     139     165     172     208     248
RY 279.8   280.5   276.0   268.0   270.5   274.0   280.5   280.2
KK   SA7
KM Runoff from Sub-Area 7
BA  0.63
PR    53       7      55      10
PW  .010    .574    .321    .095
LG  1.20     .13    6.57   .1983
US  0.93   0.843
KK   9-8
KM Routing from node 9 to node 8
RD
RC  .080    .035    .080    2800  .00482
RX  4876    4926    4979    4996    5003    5021    5051    5126
RY 301.4   301.3   301.5   291.0   291.3   300.5   299.7   299.6
KK   SA5
KM Runoff from Sub-Area 5
BA  0.78
PR     4      50      53       7      54
PW  .051    .220    .146    .375    .208
LG  1.20     .13    6.57   .1983
US  0.89   0.843
KK   C81
KM Combine Hydrographs at node 8
HC     2
KK   8-7
KM Routing from node 8 to node 7
RD
RC  .080    .035    .080    2800  .00482
RX  4876    4926    4979    4996    5003    5021    5051    5126
RY 301.4   301.3   301.5   291.0   291.3   300.5   299.7   299.6
KK GAGE4
KM Observed vs. Computed
IN     2 18OCT81    2119
QO   0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO   0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO   0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO   0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
```

Sample input for Snyder Lumped Model - Continued

```
QO    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO    0.0     0.0     0.0     0.0     5.6    11.3    15.1    20.9    35.6    53.5
QO   66.5    77.6    90.2   102.9   115.7   128.8   142.9   158.2   171.9   183.8
QO  201.8   225.9   245.2   259.8   273.4   286.1   298.2   309.6   319.2   327.2
QO  335.1   340.7   343.9   347.2   347.2   347.2   347.2   346.5   345.2   343.8
QO  339.2   331.3   323.4   315.5   307.7   303.0   301.5   300.0   298.4   296.9
QO  294.0   289.7   285.3   280.9   276.6   272.2   267.9   263.5   258.1   252.7
QO  247.3   242.5   238.4   232.8   225.8   218.9   211.9   204.9   197.9   190.9
QO  184.0   177.3   170.6   163.9   157.2   150.5   143.8   138.6   133.3   128.1
QO  122.8   117.8   113.2   108.5   103.9    99.2    95.2    91.8    88.3    84.9
QO   81.5    78.1    74.7    71.3    68.8    66.3    63.9    61.4    58.9    56.5
QO   54.0    51.5    49.1    46.6    44.4    42.6    40.8    39.0    37.2    35.6
QO   34.5    33.3    32.1    30.9    29.9    29.1    28.4    27.6    26.9    26.1
QO   25.3    24.6    23.8    23.1    22.5    22.1    21.7    21.3    20.9    20.5
QO   20.1    19.7    19.3    18.9    18.5    18.1    17.7    17.3    16.9    16.5
QO   16.1    15.7    15.3    14.9    14.5    14.1    13.7    13.5    13.2    12.9
QO   12.6    12.4    12.1    11.8    11.5    11.3    11.0    10.7    10.4    10.2
QO    9.9     9.6     9.3     9.1     8.8     8.5     8.3     8.1     7.9     7.7
QO    7.5     7.3     7.1     7.0     6.8     6.6     6.4     6.2     6.0     5.8
QO    5.7     5.6     5.5     5.4     5.3     5.2     5.1     5.0     4.8     4.7
QO    4.6     4.5     4.4     4.3     4.2     4.2     4.1     4.1     4.0     4.0
QO    3.9     3.9     3.8     3.8     3.7     3.7     3.7     3.6     3.6     3.6
QO    3.6     3.5     3.5     3.5     3.5     3.4     3.4     3.4     3.3     3.3
QO    3.3     3.3     3.2     3.2     3.2     3.2     3.1     3.1     3.1     3.0
KK    C71
KM Combine Hydrographs at node 7
HC      2
KK GAGE3
KM Observed vs. Computed
IN      2 18OCT81    2119
QO    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     2.8
QO    7.2     8.7     9.5    10.3    12.1    14.5    16.6    20.7    25.4    37.2
QO   60.9    92.9   145.8   199.3   253.4   302.2   349.7   394.5   435.3   485.8
QO  527.7   567.5   617.4   669.7   743.2   781.8   841.1   861.6   898.0   866.7
QO  956.9   995.5   984.4   956.9   984.4  1012.2  1005.6   973.4   988.5  1050.6
QO1042.2  1033.9  1025.5   956.9   946.1   935.2   913.9   935.2   978.9   946.1
QO  929.9   908.6   841.1   826.0   806.1   785.1   772.6   760.2   747.7   735.3
QO  725.6   718.6   705.9   692.2   678.6   660.8   638.9   621.8   604.7   592.3
QO  579.9   567.5   547.4   533.5   516.0   502.7   485.8   474.7   458.4   447.7
QO  435.3   424.9   414.6   401.3   388.0   376.5   368.5   362.2   354.4   340.5
QO  331.7   322.9   314.1   305.3   296.6   285.4   277.2   266.5   261.2   250.9
QO  244.5   235.8   228.4   218.9   210.7   203.9   197.0   189.2   184.9   177.4
QO  168.1   164.0   158.1   152.2   144.6   140.8   135.4   131.8   124.8   121.4
QO  118.0   113.1   108.2   105.0   100.4    97.3    92.9    90.0    88.1    85.8
QO   83.0    80.3    78.5    76.3    73.8    71.2    69.0    67.1    65.4    63.9
QO   62.3    58.1    56.6    55.2    53.7    51.6    50.0    49.0    47.5    45.5
QO   44.2    43.0    41.7    40.3    38.9    38.1    37.2    35.9    34.6    33.8
QO   33.0    31.9    31.0    30.2    29.4    28.7    28.0    27.4    26.8    26.0
QO   25.1    24.5    24.1    23.7    23.3    22.5    21.8    21.2    20.8    20.5
QO   20.1    19.6    19.1    18.8    18.5    18.2    17.9    17.6    17.3    17.0
QO   16.8    16.4    16.1    15.8    15.5    15.2    14.9    14.6    14.4    14.1
QO   13.9    13.7    13.6    13.4    13.2    13.1    12.9    12.7    12.6    12.4
QO   12.2    12.0    11.7    11.3    11.1    11.0    10.9    10.8    10.7    10.6
QO   10.5    10.4    10.3    10.2    10.0     9.9     9.7     9.5     9.4     9.2
KK    7-5
KM Routing from node 7 to node 5
RD
RC    .07    .038     .07    4070  .00381
```

Sample input for Snyder Lumped Model - Continued

```
RX  4856    4960    4972    4986    5014    5022    5040    5156
RY 262.5   264.0   257.5   252.5   253.3   256.5   264.8   263.7
KK   SA4
KM Runoff for Sub-Area 4
BA  0.60
PR    52      53      50      14
PW  .458    .345    .035    .162
LG   0.6     .13    6.57   .1983
US  0.80   0.843
KK   6-5
KM Routing from node 6 to node 5
RD
RC   .07    .038     .07    3400  .00750
RX  4856    4960    4972    4986    5014    5022    5040    5156
RY 262.5   264.0   257.5   252.5   253.3   256.5   264.8   263.7
PG     1                      10
IN     1 18OCT81    2119
PI 0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002
PI 0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002
PI 0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002
PI 0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002
PI 0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002
PI 0.002   0.002   0.002   0.002   0.005   0.005   0.005   0.005   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.039   0.039   0.039   0.039   0.039   0.039
PI 0.039   0.039   0.034   0.034   0.034   0.034   0.034   0.034   0.034   0.034
PI 0.000   0.000   0.000   0.018   0.018   0.018   0.018   0.007   0.007   0.007
PI 0.010   0.010   0.010   0.028   0.028   0.028   0.028   0.028   0.008   0.008
PI 0.008   0.008   0.008   0.022   0.022   0.022   0.022   0.022   0.022   0.051
PI 0.051   0.051   0.051   0.051   0.051   0.051   0.051   0.051   0.051   0.051
PI 0.051   0.051   0.051   0.051   0.047   0.047   0.347   0.015   0.015   0.015
PI 0.015   0.000   0.000   0.007   0.007   0.007   0.007   0.007   0.007   0.007
PI 0.007   0.007   0.007   0.007   0.007   0.007   0.007   0.007   0.005   0.005
PI 0.005   0.005   0.005   0.005   0.005   0.005   0.012   0.012   0.012   0.012
PI 0.012   0.012   0.012   0.012   0.012   0.012   0.012   0.012   0.012   0.011
PI 0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011
PI 0.050   0.004   0.004   0.004   0.004   0.004   0.004   0.004   0.004   0.004
PI 0.004
PG     2                      11
IN     1 18OCT81    2119
PI 0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
PI 0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
PI 0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
PI 0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
PI 0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
PI 0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
PI 0.003   0.003   0.003   0.003   0.027   0.027   0.027   0.004   0.004   0.004
PI 0.004   0.004   0.027   0.027   0.027   0.027   0.027   0.027   0.034   0.034
PI 0.034   0.034   0.034   0.034   0.034   0.034   0.034   0.034   0.034   0.034
PI 0.034   0.034   0.000   0.000   0.000   0.008   0.008   0.008   0.008   0.008
PI 0.008   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021
PI 0.022   0.022   0.022   0.022   0.022   0.022   0.022   0.022   0.022   0.022
PI 0.022   0.022   0.022   0.022   0.054   0.054   0.054   0.054   0.054   0.054
PI 0.054   0.054   0.054   0.033   0.033   0.033   0.033   0.033   0.033   0.033
PI 0.033   0.013   0.013   0.013   0.013   0.013   0.013   0.013   0.013   0.013
PI 0.013   0.000   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009
PI 0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009
PI 0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009
PI 0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009
PI 0.009   0.009   0.009   0.009   0.009   0.009   0.004   0.004   0.004   0.004
PI 0.004   0.004   0.004   0.004   0.004   0.004   0.004   0.004   0.004   0.004
PI 0.004
KK   SA3
KM Runoff from Sub-Area 3
BA  0.90
```

Sample input for Snyder Lumped Model - Continued

```
PR     2      13      14      50       4       6
PW  .389    .244    .164    .071    .114    .018
LG   0.6     .13    6.57   .1983
US  0.97   0.843
KK   C51
KM Combine Hydrographs at node 5
HC     3
KK   5-3
KM Routing from node 5 to node 3
RD
RC   .07    .038     .07    4144  .00193
RX  4856    4960    4972    4986    5014    5022    5040    5156
RY 262.5   264.0   257.5   252.5   253.3   256.5   264.8   263.7
KK   SA2
KM Runoff from Sub-Area 2
BA  0.60
PR    51      52      14      13       2
PW  .485    .288    .048    .157    .022
LG   0.6     .13    6.57   .1983
US  1.11   0.843
KK   4-3
KM Routing from node 4 to node 3
RD
RC   .07    .038     .07    6345  .00750
RX  4856    4960    4972    4986    5014    5022    5040    5156
RY 262.5   264.0   257.5   252.5   253.3   256.5   264.8   263.7
KK   C31
KM Combine hydrographs at node 3
HC     2
KK GAGE2
KM Observed vs. Computed
IN     2 18OCT81    2119
QO   0.6     0.6     0.6     0.6     0.6     0.6     0.6     0.6     0.6     0.6
QO   0.6     0.6     0.6     0.6     0.6     0.6     0.6     0.6     0.6     0.6
QO   0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7
QO   0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7
QO   0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.8
QO   0.9     1.0     1.0     1.0     1.0     1.0     1.0     1.0     1.0     1.0
QO   1.0     1.0     1.0     1.0     1.0     1.0     1.0     4.3     4.6     6.1
QO   8.9    13.2    18.1    22.4    26.5    30.2    34.2    40.3    45.2    51.2
QO  58.7    69.3    81.3    95.1   112.2   129.1   147.4   165.0   190.3   232.1
QO 299.4   375.9   447.6   531.1   610.6   699.2   778.6   864.7   948.2  1022.5
QO1083.6  1129.9  1188.3  1231.7  1270.4  1304.1  1332.3  1372.5  1407.4  1423.1
QO1442.8  1460.7  1472.7  1484.7  1496.7  1527.1  1527.1  1527.1  1527.1  1527.1
QO1527.1  1527.1  1527.1  1527.1  1541.4  1533.2  1521.0  1502.8  1495.5  1488.3
QO1472.7  1456.2  1447.3  1439.9  1433.9  1427.4  1420.4  1413.3  1375.4  1349.5
QO1332.3  1301.2  1270.5  1220.8  1213.5  1201.8  1172.2  1140.4  1116.0  1093.5
QO1073.0  1037.5  1002.1   973.8   948.2   918.7   884.4   861.1   838.1   813.0
QO 788.4   768.9   749.8   712.3   694.3   676.3   658.3   631.9   620.5   604.3
QO 581.4   565.0   545.0   521.4   502.4   487.3   468.8   461.6   450.8   436.7
QO 421.1   409.2   399.1   382.7   369.9   357.1   350.9   337.2   326.7   314.9
QO 303.4   294.9   286.5   277.0   267.6   258.4   249.3   244.3   234.3   227.0
QO 222.2   216.3   209.4   202.4   196.7   191.2   185.7   180.4   174.1   169.6
QO 166.9   160.8   157.0   153.3   149.5   145.7   141.9   138.2   134.4   131.2
QO 128.5   126.3   124.6   122.1   118.7   115.4   112.0   109.9   107.2   104.1
QO 101.8    99.5    97.5    95.5    93.5    90.6    88.4    86.3    84.9    83.5
QO  81.7    79.9    78.1    75.5    73.4    71.9    70.4    69.2    67.9    66.4
QO  64.8    63.3    61.7    60.2    58.6    57.1    55.5    53.9    52.6    51.8
QO  50.9    50.0    49.0    48.0    47.0    46.0    45.0    44.0    43.0    42.1
QO  41.3    40.6    39.8    38.9    38.0    37.1    36.3    35.6    35.0    34.5
QO  34.0    33.6    33.1    32.6    32.1    31.7    31.5    31.2    31.0    30.8
QO  30.6    30.3    30.1    29.7    29.2    28.7    28.3    27.8    27.5    27.3
KK   3-2
KM Routing from node 3 to node 2
RD
RC  .070    .037    .070    5743  .00293
```

Sample input for Snyder Lumped Model - Continued

```
RX 4900     4931     4961     4985     5000     5039     5070     5100
RY 240.0    236.0    234.0    223.0    220.0    234.0    236.0    240.0
KK  SA1
KM Runoff from Sub-Area 1
BA  1.44
PR     1        2       51
PW  .375     .271     .354
LG   0.6      .13     6.57    .1983
US  1.28    0.843
KK   C21
KM Combine hydrographs at node 2
HC     2
KK   2-1
KM Routing from node 2 to node 1
RD
RC  .070     .037     .070     5743   .00155
RX  4900     4931     4961     4985     5000     5039     5070     5100
RY 240.0    236.0    234.0    223.0    220.0    234.0    236.0    240.0
KK GAGE1
KM Observed vs. Computed
IN      2 18OCT81     2119
QO   1.0      1.0      1.0      1.0      1.0      1.1      1.1      1.1      1.1      1.1
QO   1.1      1.1      1.1      1.1      1.1      1.1      1.1      1.1      1.1      1.2
QO   1.2      1.2      1.2      1.2      1.2      1.2      1.2      1.2      1.2      1.2
QO   1.2      1.2      1.2      1.3      1.3      1.3      1.3      1.3      1.4      1.4
QO   1.4      1.9      2.3      2.7      3.2      3.6      4.1      4.5      4.7      4.7
QO   4.7      4.7      4.7      4.7      5.1      5.9      7.5      9.1      9.9     10.7
QO  11.5     12.3     13.1     13.9     14.7     15.5     17.0     18.4     19.8     21.2
QO  22.7     25.8     29.0     32.6     36.7     40.8     45.9     50.9     56.0     61.1
QO  66.2     67.5     68.7     69.9     71.2     70.4     69.7     69.0     68.3     67.6
QO  66.9     66.2     66.2     66.2     70.0     73.7     87.8    101.9    139.1    176.4
QO 225.4    274.5    354.9    435.3    477.6    519.9    577.7    638.9    693.4    747.9
QO 807.3    866.7    906.4    946.0    995.8   1045.6   1083.7   1122.6   1154.4   1186.2
QO1210.6   1235.0   1259.8   1284.9   1301.8   1318.7   1334.7   1350.7   1364.4   1376.0
QO1387.6   1393.4   1399.3   1405.1   1405.1   1405.1   1402.8   1400.4   1398.1   1395.7
QO1393.4   1386.5   1379.5   1372.6   1365.6   1358.7   1341.6   1324.6   1307.6   1290.7
QO1273.7   1287.1   1300.7   1314.3   1327.9   1341.4   1287.4   1234.5   1182.7   1130.9
QO1081.1   1065.1   1049.0   1032.9   1016.8   1000.7    982.2    963.8    945.4    926.9
QO 908.5    882.3    857.1    831.9    806.7    781.5    757.4    734.4    711.3    688.3
QO 665.2    646.9    628.5    610.9    593.2    575.6    560.3    545.0    530.1    515.3
QO 500.8    487.5    474.2    460.9    448.1    435.3    424.7    414.1    403.4    393.1
QO 383.0    373.2    363.4    353.6    343.8    334.4    326.9    319.4    311.9    304.3
QO 296.8    289.3    282.3    275.3    268.2    261.2    254.3    247.6    240.9    234.3
QO 227.6    221.0    214.3    208.0    201.9    195.8    191.2    186.6    182.2    177.9
QO 173.5    169.1    164.8    160.4    156.4    152.2    149.0    145.7    142.5    139.5
QO 136.4    133.4    130.3    127.3    124.2    121.3    118.9    116.4    113.9    111.4
QO 109.0    106.6    104.3    102.0     99.7     97.3     95.8     94.2     92.7     91.1
QO  89.6     88.0     86.5     85.1     83.6     82.1     80.7     79.2     77.8     76.4
QO  75.0     73.6     72.3     71.0     69.7     68.4     67.1     65.7     64.4     63.2
QO  62.0     60.8     59.5     58.3     57.1     55.9     54.9     54.0     53.0     52.0
QO  51.1     50.2     49.3     48.3     47.4     46.5     45.7     45.0     44.2     43.5
ZW    A=DEC    B=GOODWIN    C=FLOW    F=CAL
ZZ
```

Sample input for Snyder Lumped Model - Continued

```
ID GOODWIN CREEK WATERSHED
ID SCS METHOD    6/22/93  10:15 AM
IT       2 18OCT81      2119      300
IO
PG       4
IN       1 18OCT81      2119
PI 0.000   0.000   0.000   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.020   0.020   0.020   0.020
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.022   0.022   0.022
PI 0.022   0.022   0.022   0.022   0.022   0.022   0.003   0.003   0.003   0.003
PI 0.003   0.003   0.013   0.013   0.013   0.013   0.013   0.013   0.013   0.013
PI 0.013   0.013   0.043   0.043   0.043   0.043   0.043   0.043   0.043   0.043
PI 0.043   0.043   0.043   0.043   0.016   0.016   0.016   0.016   0.016   0.016
PI 0.016   0.016   0.000   0.000   0.000   0.000   0.000   0.019   0.019   0.019
PI 0.019   0.019   0.019   0.019   0.019   0.019   0.019   0.019   0.019   0.020
PI 0.020   0.020   0.020   0.020   0.020   0.020   0.020   0.020   0.020   0.020
PI 0.020   0.020   0.020   0.049   0.049   0.049   0.049   0.049   0.04
PI 0.035   0.035   0.035   0.035   0.035   0.035   0.035   0.035   0.03
PI 0.035   0.000   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009
PI 0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.005   0.005
PI 0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
PI 0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
PI 0.005   0.005   0.020   0.020   0.020   0.020   0.020   0.020   0.012   0.012
PI 0.012   0.012   0.012   0.012   0.012   0.012   0.012   0.012   0.050   0.004
PI 0.004
PG       5
IN       1 18OCT81      2119
PI 0.000   0.000   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.014   0.014   0.014   0.014   0.014   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.004   0.004   0.004   0.004
PI 0.004   0.025   0.025   0.025   0.025   0.025   0.025   0.025   0.025   0.025
PI 0.025   0.025   0.013   0.013   0.013   0.013   0.013   0.013   0.013   0.013
PI 0.013   0.013   0.013   0.013   0.013   0.030   0.030   0.030   0.030   0.030
PI 0.030   0.030   0.030   0.030   0.030   0.030   0.030   0.037   0.037   0.037
PI 0.037   0.037   0.037   0.037   0.000   0.000   0.000   0.000   0.000   0.010
PI 0.010   0.010   0.010   0.016   0.016   0.016   0.016   0.016   0.016   0.016
PI 0.016   0.016   0.016   0.016   0.016   0.016   0.016   0.016   0.016   0.016
PI 0.016   0.016   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
PI 0.040   0.062   0.062   0.062   0.062   0.062   0.029   0.029   0.029   0.029
PI 0.029   0.029   0.029   0.010   0.010   0.010   0.010   0.010   0.010   0.010
PI 0.000   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.007   0.007   0.007
PI 0.007   0.007   0.007   0.007   0.007   0.007   0.007   0.007   0.007   0.007
PI 0.007   0.007   0.007   0.007   0.007   0.020   0.020   0.020   0.020   0.020
PI 0.020   0.020   0.012   0.012   0.012   0.012   0.012   0.012   0.025   0.025
PI 0.025   0.025   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
PI 0.003
PG       6
IN       1 18OCT81      2119
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.008   0.008   0.008   0.008   0.008   0.008   0.008   0.008
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.027   0.027   0.027   0.027   0.027   0.027
PI 0.027   0.027   0.027   0.027   0.027   0.027   0.018   0.018   0.018   0.018
PI 0.018   0.018   0.018   0.018   0.018   0.018   0.018   0.018   0.018   0.018
PI 0.018   0.070   0.015   0.015   0.015   0.015   0.015   0.015   0.039   0.039
PI 0.039   0.039   0.039   0.039   0.039   0.039   0.039   0.039   0.005   0.005
PI 0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
PI 0.031   0.031   0.031   0.031   0.031   0.031   0.031   0.031   0.031   0.031
```

Sample input for SCS Lumped Model

```
PI 0.031   0.031   0.031   0.031   0.031   0.031   0.031   0.031   0.031   0.031
PI 0.031   0.031   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
PI 0.040   0.040   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
PI 0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.010   0.010   0.010   0.010
PI 0.010   0.010   0.010   0.010   0.010   0.010   0.010   0.010   0.020   0.020
PI 0.020   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
PI 0.005
PG       7
IN       1 18OCT81    2119
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.014   0.014   0.014   0.014   0.014   0.014   0.014   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
PI 0.008   0.008   0.008   0.008   0.008   0.008   0.008   0.008   0.008   0.008
PI 0.008   0.008   0.032   0.032   0.032   0.032   0.032   0.032   0.032   0.032
PI 0.032   0.046   0.046   0.046   0.046   0.046   0.046   0.046   0.003   0.003
PI 0.003   0.003   0.016   0.016   0.016   0.016   0.016   0.016   0.016   0.016
PI 0.016   0.016   0.016   0.016   0.016   0.011   0.011   0.011   0.011   0.011
PI 0.011   0.011   0.025   0.025   0.025   0.025   0.042   0.042   0.042   0.042
PI 0.042   0.042   0.042   0.042   0.042   0.042   0.042   0.045   0.045   0.045
PI 0.045   0.045   0.045   0.045   0.045   0.040   0.040   0.040   0.040   0.040
PI 0.060   0.080   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011
PI 0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.035   0.035   0.035
PI 0.035   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.000
PI 0.000
PG       8
IN       1 18OCT81    2119
PI 0.000   0.000   0.000   0.004   0.004   0.004   0.004   0.004   0.004   0.004
PI 0.004   0.004   0.004   0.004   0.004   0.004   0.004   0.004   0.004   0.007
PI 0.007   0.007   0.007   0.007   0.007   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.027   0.027   0.027   0.027   0.027
PI 0.027   0.018   0.018   0.018   0.018   0.018   0.018   0.018   0.018   0.018
PI 0.018   0.018   0.022   0.022   0.022   0.022   0.022   0.022   0.022   0.022
PI 0.022   0.023   0.023   0.023   0.023   0.023   0.023   0.023   0.023   0.023
PI 0.023   0.023   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
PI 0.040   0.005   0.005   0.005   0.005   0.005   0.005   0.018   0.018   0.018
PI 0.018   0.018   0.018   0.018   0.018   0.018   0.018   0.018   0.018   0.017
PI 0.017   0.017   0.017   0.017   0.017   0.017   0.017   0.017   0.017   0.017
PI 0.017   0.017   0.017   0.069   0.069   0.069   0.069   0.069   0.069   0.069
PI 0.069   0.069   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.025   0.025   0.020   0.020   0.005   0.005   0.005   0.005   0.005
PI 0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
PI 0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
PI 0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
PI 0.023   0.023   0.023   0.023   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.017   0.017
PI 0.017
PG      10
IN       1 18OCT81    2119
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.020   0.020   0.020   0.020   0.020   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.031   0.031   0.031   0.031   0.031   0.031
```

Sample input for SCS Lumped Model - Continued

```
PI 0.031  0.031  0.031  0.031  0.031  0.002  0.002  0.002  0.002  0.002
PI 0.035  0.035  0.035  0.035  0.010  0.010  0.010  0.010  0.010  0.010
PI 0.010  0.033  0.033  0.033  0.033  0.033  0.033  0.033  0.033  0.033
PI 0.033  0.033  0.033  0.033  0.033  0.033  0.033  0.033  0.033  0.033
PI 0.004  0.004  0.004  0.004  0.004  0.020  0.020  0.020  0.020  0.020
PI 0.020  0.020  0.020  0.020  0.020  0.020  0.020  0.030  0.030  0.030
PI 0.030  0.030  0.030  0.030  0.030  0.030  0.030  0.030  0.030  0.030
PI 0.030  0.030  0.030  0.030  0.030  0.030  0.030  0.030  0.030  0.030
PI 0.030  0.030  0.030  0.016  0.016  0.016  0.016  0.016  0.016  0.016
PI 0.016  0.000  0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006
PI 0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006
PI 0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006
PI 0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006
PI 0.006  0.019  0.019  0.019  0.019  0.019  0.019  0.019  0.019  0.019
PI 0.010  0.010  0.010  0.010  0.010  0.010  0.010  0.050  0.050  0.003
PI 0.003
PG    11
IN     1 18OCT81   2119
PI 0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000
PI 0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000
PI 0.000  0.000  0.000  0.005  0.005  0.030  0.030  0.030  0.001  0.001
PI 0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001
PI 0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001
PI 0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001
PI 0.001  0.001  0.001  0.001  0.001  0.017  0.017  0.017  0.050  0.050
PI 0.050  0.050  0.023  0.023  0.023  0.023  0.023  0.023  0.023  0.008
PI 0.008  0.008  0.008  0.008  0.050  0.050  0.013  0.013  0.013  0.010
PI 0.010  0.010  0.025  0.025  0.025  0.025  0.025  0.025  0.064  0.064
PI 0.064  0.064  0.064  0.026  0.026  0.026  0.026  0.026  0.007  0.007
PI 0.007  0.002  0.002  0.002  0.002  0.002  0.007  0.007  0.007  0.007
PI 0.007  0.007  0.042  0.042  0.042  0.042  0.042  0.011  0.011  0.011
PI 0.011  0.011  0.011  0.011  0.011  0.011  0.028  0.028  0.028  0.028
PI 0.028  0.045  0.045  0.045  0.045  0.080  0.080  0.037  0.037  0.037
PI 0.040  0.050  0.020  0.020  0.020  0.020  0.020  0.011  0.011  0.011
PI 0.011  0.011  0.011  0.011  0.006  0.006  0.006  0.006  0.006  0.006
PI 0.006  0.006  0.006  0.006  0.005  0.005  0.005  0.005  0.005  0.005
PI 0.005  0.005  0.005  0.005  0.005  0.005  0.005  0.005  0.005  0.006
PI 0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.080  0.012
PI 0.012  0.012  0.012  0.012  0.012  0.009  0.009  0.009  0.009  0.009
PI 0.009
PG    13
IN     1 18OCT81   2119
PI 0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000
PI 0.000  0.023  0.023  0.023  0.001  0.001  0.001  0.001  0.001  0.001
PI 0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001
PI 0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001
PI 0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001
PI 0.001  0.001  0.001  0.001  0.012  0.012  0.012  0.012  0.012  0.012
PI 0.012  0.012  0.012  0.012  0.003  0.003  0.003  0.003  0.003  0.003
PI 0.003  0.018  0.018  0.018  0.018  0.006  0.006  0.006  0.006  0.006
PI 0.034  0.034  0.034  0.034  0.034  0.034  0.034  0.034  0.034  0.034
PI 0.034  0.034  0.034  0.034  0.034  0.034  0.034  0.002  0.002  0.002
PI 0.002  0.002  0.015  0.015  0.018  0.018  0.018  0.018  0.018  0.018
PI 0.018  0.018  0.018  0.018  0.018  0.018  0.010  0.010  0.010  0.010
PI 0.010  0.010  0.010  0.010  0.041  0.041  0.041  0.041  0.041  0.041
PI 0.041  0.041  0.041  0.041  0.041  0.041  0.041  0.041  0.041  0.041
PI 0.041  0.041  0.041  0.018  0.018  0.018  0.018  0.018  0.018  0.018
PI 0.018  0.020  0.020  0.007  0.007  0.007  0.007  0.007  0.007  0.007
PI 0.007  0.007  0.007  0.007  0.007  0.007  0.007  0.006  0.006  0.006
PI 0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006  0.006
PI 0.006  0.006  0.006  0.006  0.006  0.013  0.013  0.013  0.013  0.013
PI 0.013  0.013  0.013  0.013  0.013  0.013  0.011  0.011  0.011  0.011
PI 0.011  0.011  0.011  0.011  0.011  0.004  0.004  0.004  0.004  0.004
PI 0.004
PG    14
IN     1 18OCT81   2119
```

Sample input for SCS Lumped Model - Continued

```
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.020   0.020   0.020   0.020   0.020   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.033   0.033   0.033   0.013
PI 0.013   0.013   0.013   0.013   0.013   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.010   0.010   0.010   0.010   0.010   0.010   0.010   0.010
PI 0.036   0.036   0.036   0.036   0.036   0.036   0.036   0.036   0.036   0.036
PI 0.036   0.036   0.036   0.036   0.036   0.036   0.036   0.036   0.003   0.003
PI 0.003   0.003   0.003   0.003   0.008   0.008   0.008   0.008   0.008   0.008
PI 0.028   0.028   0.028   0.028   0.028   0.028   0.032   0.032   0.032   0.032
PI 0.032   0.032   0.032   0.032   0.032   0.032   0.032   0.032   0.032   0.032
PI 0.032   0.032   0.032   0.032   0.032   0.037   0.037   0.037   0.037   0.037
PI 0.037   0.037   0.037   0.037   0.014   0.014   0.014   0.014   0.014   0.014
PI 0.014   0.010   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009
PI 0.009   0.009   0.009   0.009   0.009   0.009   0.005   0.005   0.005   0.005
PI 0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
PI 0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.013   0.013   0.013
PI 0.013   0.013   0.013   0.013   0.013   0.013   0.013   0.013   0.013   0.013
PI 0.013   0.013   0.013   0.013   0.013   0.003   0.003   0.003   0.003   0.003
PI 0.003
PI 0.171
PG     50
IN      1 18OCT81    2119
PI 0.000   0.004   0.004   0.004   0.004   0.004   0.004   0.040   0.040   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.020   0.020   0.020
PI 0.020   0.020   0.020   0.020   0.020   0.020   0.020   0.003   0.003   0.003
PI 0.003   0.003   0.003   0.003   0.020   0.020   0.020   0.020   0.027   0.027
PI 0.027   0.027   0.027   0.027   0.027   0.027   0.027   0.027   0.027   0.027
PI 0.027   0.027   0.027   0.027   0.027   0.027   0.027   0.027   0.027   0.027
PI 0.027   0.027   0.027   0.027   0.000   0.000   0.000   0.025   0.025   0.015
PI 0.015   0.015   0.015   0.015   0.015   0.015   0.015   0.015   0.015   0.015
PI 0.015   0.015   0.015   0.015   0.024   0.024   0.024   0.024   0.024   0.024
PI 0.024   0.024   0.024   0.024   0.051   0.051   0.051   0.051   0.051   0.051
PI 0.051   0.051   0.043   0.043   0.043   0.043   0.043   0.043   0.043   0.013
PI 0.013   0.013   0.013   0.013   0.013   0.013   0.013   0.013   0.013   0.013
PI 0.080   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002
PI 0.002   0.002   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.017   0.017   0.017   0.017   0.017   0.017   0.017
PI 0.010   0.010   0.010   0.010   0.010   0.010   0.010   0.010   0.010   0.020
PI 0.020   0.020   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
PI 0.005
PG     51
IN      1 18OCT81    2119
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.018   0.018   0.018   0.018   0.006   0.006   0.006   0.006
PI 0.006   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.017   0.017   0.017
PI 0.008   0.008   0.008   0.008   0.008   0.008   0.002   0.002   0.002   0.002
PI 0.002   0.002   0.030   0.030   0.007   0.007   0.007   0.011   0.011   0.011
PI 0.011   0.011   0.011   0.011   0.036   0.036   0.036   0.036   0.036   0.036
PI 0.036   0.057   0.057   0.057   0.035   0.035   0.033   0.033   0.033   0.003
PI 0.003   0.003   0.003   0.003   0.003   0.003   0.040   0.005   0.005   0.005
PI 0.005   0.024   0.024   0.024   0.024   0.024   0.023   0.023   0.023   0.010
PI 0.010   0.010   0.010   0.010   0.010   0.028   0.028   0.028   0.028   0.028
PI 0.033   0.033   0.033   0.033   0.033   0.033   0.103   0.103   0.103   0.033
PI 0.033   0.033   0.033   0.030   0.030   0.030   0.030   0.030   0.030   0.030
PI 0.000   0.000   0.013   0.013   0.013   0.013   0.013   0.013   0.013   0.015
PI 0.015   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
```

Sample input for SCS Lumped Model - Continued

```
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.010   0.010   0.010   0.025   0.025   0.008   0.008   0.008   0.008
PI 0.008   0.008   0.023   0.023   0.023   0.003   0.003   0.003   0.003   0.003
PI 0.003
PG    52
IN     1 180CT81   2119
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.017   0.017   0.017   0.017   0.017   0.017   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.016   0.016   0.016   0.016
PI 0.016   0.013   0.013   0.013   0.004   0.004   0.004   0.004   0.004   0.004
PI 0.004   0.005   0.005   0.005   0.005   0.015   0.015   0.015   0.015   0.015
PI 0.015   0.015   0.015   0.048   0.048   0.048   0.048   0.048   0.048   0.048
PI 0.048   0.020   0.020   0.020   0.020   0.020   0.020   0.020   0.020   0.020
PI 0.000   0.000   0.000   0.017   0.017   0.017   0.003   0.003   0.003   0.003
PI 0.032   0.032   0.032   0.032   0.032   0.032   0.009   0.009   0.009   0.009
PI 0.009   0.009   0.009   0.009   0.025   0.025   0.025   0.025   0.025   0.025
PI 0.054   0.054   0.054   0.054   0.054   0.054   0.054   0.054   0.054   0.054
PI 0.054   0.035   0.035   0.035   0.035   0.017   0.017   0.017   0.017   0.017
PI 0.017   0.000   0.012   0.012   0.012   0.012   0.012   0.012   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.011
PI 0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.010
PI 0.010   0.020   0.020   0.020   0.020   0.002   0.002   0.002   0.002   0.002
PI 0.002
PG    53
IN     1 180CT81   2119
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.007   0.007   0.007   0.007   0.007
PI 0.007   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
PI 0.000   0.000   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002
PI 0.002   0.014   0.014   0.014   0.014   0.014   0.014   0.014   0.003   0.003
PI 0.003   0.017   0.017   0.017   0.017   0.017   0.017   0.017   0.018   0.018
PI 0.018   0.018   0.018   0.018   0.027   0.027   0.027   0.027   0.027   0.027
PI 0.027   0.045   0.045   0.033   0.033   0.033   0.033   0.035   0.035   0.035
PI 0.035   0.002   0.002   0.002   0.002   0.002   0.002   0.010   0.010   0.010
PI 0.003   0.003   0.003   0.012   0.012   0.012   0.012   0.012   0.120   0.011
PI 0.011   0.011   0.011   0.011   0.011   0.011   0.017   0.017   0.017   0.017
PI 0.017   0.017   0.050   0.050   0.010   0.010   0.067   0.067   0.067   0.050
PI 0.050   0.050   0.050   0.033   0.033   0.033   0.023   0.023   0.023   0.025
PI 0.025   0.007   0.007   0.007   0.007   0.007   0.007   0.007   0.007   0.007
PI 0.007   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
PI 0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.008   0.008   0.008   0.008   0.008   0.008   0.028   0.020   0.020
PI 0.005   0.005   0.005   0.005   0.005   0.005   0.018   0.018   0.018   0.018
PI 0.003
PG    54
IN     1 180CT81   2119
PI 0.000   0.000   0.016   0.016   0.016   0.016   0.016   0.016   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.053   0.053
PI 0.053   0.014   0.014   0.014   0.014   0.014   0.014   0.014   0.006   0.006
PI 0.006   0.006   0.006   0.027   0.027   0.027   0.028   0.028   0.028   0.028
PI 0.028   0.028   0.028   0.028   0.028   0.028   0.028   0.028   0.028   0.028
PI 0.028   0.028   0.030   0.030   0.030   0.030   0.030   0.030   0.007   0.007
PI 0.007   0.007   0.007   0.007   0.007   0.012   0.012   0.012   0.012   0.012
PI 0.012   0.018   0.018   0.018   0.018   0.018   0.018   0.016   0.016   0.016
```

Sample input for SCS Lumped Model - Continued

```
PI 0.016   0.016   0.016   0.016   0.016   0.016   0.016   0.016   0.016   0.016
PI 0.016   0.050   0.050   0.050   0.050   0.050   0.050   0.050   0.050   0.035
PI 0.035   0.035   0.035   0.035   0.035   0.035   0.035   0.011   0.011   0.011
PI 0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011
PI 0.011   0.000   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.026
PI 0.026   0.026   0.026   0.026   0.007   0.007   0.007   0.007   0.007   0.007
PI 0.007   0.007   0.007   0.007   0.015   0.015   0.015   0.015   0.002   0.002
PI 0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002
PI 0.002
PG    55
IN     1 18OCT81    2119
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.020   0.020   0.020   0.020   0.020   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.024   0.024   0.024
PI 0.024   0.024   0.024   0.024   0.024   0.024   0.024   0.024   0.024   0.024
PI 0.003   0.003   0.003   0.003   0.032   0.032   0.032   0.032   0.032   0.007
PI 0.007   0.007   0.024   0.024   0.024   0.024   0.024   0.024   0.024   0.024
PI 0.024   0.024   0.024   0.024   0.024   0.024   0.036   0.036   0.036   0.036
PI 0.036   0.036   0.036   0.036   0.004   0.004   0.004   0.004   0.004   0.004
PI 0.004   0.015   0.015   0.005   0.005   0.021   0.021   0.021   0.021   0.021
PI 0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021
PI 0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021
PI 0.021   0.049   0.049   0.049   0.049   0.049   0.049   0.049   0.090   0.090
PI 0.090   0.000   0.040   0.040   0.040   0.040   0.040   0.040   0.009   0.009
PI 0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009
PI 0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.007   0.007   0.007
PI 0.007   0.007   0.007   0.007   0.007   0.007   0.007   0.007   0.007   0.007
PI 0.007   0.007   0.007   0.007   0.007   0.009   0.009   0.009   0.009   0.009
PI 0.009   0.009   0.009   0.009   0.002   0.002   0.002   0.002   0.002   0.001
PI 0.001
KK  SA14
KM Runoff for Sub-Area 14
BA  0.14
PR    11
PW     1
LG  1.20     .13    6.57   .1983
UD  0.51
KK 18-17
KM Routing from node 18 to node 17
RD
RC   .08     .04     .08    2075  .00410
RX  4949    4950    4975    4996    5004    5025    5030    5050
RY 343.0   342.0   337.0   327.0   327.0   337.0   342.0   342.0
KK  SA13
BA  0.31
PR     8      11
PW  .299    .701
LG  1.20     .13    6.57   .1983
UD  0.99
KK  C171
KM Combine Hydrographs at node 17
HC     2
KK 17-15
KM Routing from node 17 to node 15
RD
RC   .08     .04     .08    2075  .00386
RX  4949    4950    4975    4996    5004    5025    5030    5050
RY 343.0   342.0   337.0   327.0   327.0   337.0   342.0   342.0
KK  SA11
KM Runoff for Sub-Area 11
BA  0.17
```

Sample input for SCS Lumped Model - Continued

```
PR    10     11
PW  .262   .737
LG  1.20    .13    6.57   .1983
UD  0.63
KK 16-15
KM Routing from node 16 to node 15
RD
RC   .08    .04     .08   2500  .00400
RX  4949   4950    4975   4996   5004    5025    5030    5050
RY 343.0  342.0   337.0  327.0  327.0   337.0   342.0   342.0
KK  SA12
KM Runoff for Sub-Area 12
BA  0.07
PR     8
PW     1
LG  1.20    .13    6.57   .1983
UD  0.58
KK  C151
KM Combine Hydrographs at node 15
HC     3
KK GAGE8
KM Observed vs. Computed
IN     2 18OCT81   2119
QO   0.0    0.0     0.0    0.0    0.0     0.0     0.0     0.0     0.0     0.0
QO   0.0    0.0     0.0    0.0    0.0     0.0     0.0     0.0     0.0     0.0
QO   0.0    0.0     0.0    0.0    0.0     0.0     0.0     0.0     0.0     0.0
QO   0.0    0.0     0.0    0.0    0.0     0.0     0.0     0.1     0.1     0.1
QO   0.1    0.1     0.1    0.1    0.1     0.1     0.1     0.1     0.1     0.1
QO   0.1    0.1     0.1    0.1    0.2     0.2     0.2     0.1     0.1     0.1
QO   0.1    0.1     0.1    0.1    0.3     1.8     6.2    12.7    20.3    27.7
QO  33.1   38.5    43.8   48.2   53.4    59.0    65.0    72.0    79.5    84.7
QO  92.8  100.4   108.5  120.4  132.7   148.3   163.7   178.4   192.5   205.7
QO 216.3  228.8   238.5  245.1  251.7   255.1   260.2   259.1   258.1   257.1
QO 256.1  255.1   250.0  245.0  236.8   230.4   221.7   214.8   205.7   199.7
QO 191.0  183.9   177.0  170.2  164.9   158.4   153.9   148.3   143.4   139.8
QO 135.0  132.7   129.2  127.7  126.2   124.7   121.4   119.2   117.0   114.9
QO 112.7  110.6   108.5  105.4  103.4   100.4    98.5    95.7    92.9    90.1
QO  87.4   84.3    81.6   79.5   77.0    74.1    71.6    69.3    66.9    64.6
QO  62.7   60.5    57.6   54.1   52.8    51.1    49.2    47.3    45.4    43.5
QO  41.7   40.0    38.5   37.4   36.0    34.4    32.8    31.6    30.3    28.9
QO  27.4   26.3    24.9   23.6   22.8    21.9    20.9    19.9    19.0    18.2
QO  17.7   17.0    16.5   15.9   15.2    14.6    14.1    13.6    13.0    12.6
QO  12.1   11.5    11.1   10.8   10.5    10.2     9.8     9.5     9.2     9.0
QO   8.7    8.4     8.1    7.8    7.6     7.4     7.1     6.9     6.7     6.5
QO   6.3    6.2     6.1    5.9    5.8     5.6     5.5     5.3     5.2     5.1
QO   5.0    4.8     4.7    4.5    4.4     4.3     4.2     4.1     4.0     3.9
QO   3.8    3.8     3.7    3.6    3.5     3.3     3.2     3.1     3.1     3.0
QO   2.9    2.9     2.8    2.7    2.7     2.6     2.6     2.5     2.5     2.4
QO   2.4    2.3     2.3    2.2    2.2     2.1     2.1     2.1     2.0     2.0
QO   2.0    1.9     1.9    1.9    1.8     1.8     1.8     1.7     1.7     1.7
QO   1.6    1.6     1.5    1.5    1.5     1.4     1.4     1.4     1.4     1.3
QO   1.3    1.3     1.3    1.3    1.2     1.2     1.2     1.2     1.2     1.2
QO   1.1    1.1     1.1    1.1    1.1     1.1     1.0     1.0     1.0     1.0
KK 15-14
KM Routing from node 15 to node 14
RD
RC   .08    .04     .08   3800  .00513
RX  4848   4948    4954   4968   5031    5046    5098    5148
RY 338.5  336.5   337.0  329.0  320.5   335.0   336.5   336.5
KK   SA9
KM Runoff for Sub-Area 9
BA  0.86
PR     5     55      10      8
PW  .258   .242    .123   .377
LG  1.20    .13    6.57  .1983
UD  1.47
```

Sample input for SCS Lumped Model - Continued

```
KK  C141
KM Combine Hydrographs at node 14
HC      2
KK 14-12
KM Routing from node 14 to node 12
RD
RC    .08      .04      .08     3800  .00342
RX   4848     4948     4954     4968    5031     5046     5098     5148
RY  338.5    336.5    337.0    329.0   320.5    335.0    336.5    336.5
KK  SA10
KM Runoff for Sub-Area 10
BA   0.15
PR     10       11
PW   .949     .051
LG   1.20      .13     6.57    .1983
UD   0.57
KK 13-12
KM Routing from node 13 to node 12
RD
RC   .100     .040     .100     5500  .00791
RX     20       70      120      127     144      160      220      270
RY  331.0    329.2    328.5    319.8   314.0    329.5    329.6    330.5
KK  C121
KM Combine hydrographs at node 12
HC      2
KK GAGES
KM Observed vs. Computed
IN      2 18OCT81     2119
QO    0.0      0.0      0.0      0.0     0.0      0.0      0.0      0.0      0.0      0.0
QO    0.0      0.0      0.0      0.0     0.0      0.0      0.0      0.0      0.0      0.0
QO    0.0      0.0      0.0      0.0     0.0      0.0      0.0      0.0      0.0      0.0
QO    0.0      0.0      0.0      0.0     0.0      0.0      0.0      0.0      0.0      0.0
QO    0.0      0.0      0.0      0.0     0.0      0.0      0.0      0.0      0.0      0.0
QO    0.0      0.0      0.0      0.0     0.1      0.1      0.1      0.1      0.1      3.9
QO   12.3     15.6     18.5     21.4    25.4     32.9     42.8     50.8     57.1     61.6
QO   64.8     68.8     71.3     75.5    80.8     88.3     95.9    108.4    122.7    138.9
QO  158.1    176.9    198.7    220.1   244.8    270.6    292.7    313.3    337.0    357.6
QO  380.9    400.7    425.5    448.9   473.0    495.4    513.1    527.3    539.0    547.0
QO  554.9    560.3    559.5    558.6   557.8    557.0    556.1    555.3    550.9    544.3
QO  537.7    528.5    520.8    515.6   508.0    500.5    492.9    485.3    475.5    465.8
QO  456.1    448.9    438.3    429.0   421.0    409.7    400.9    392.1    383.3    374.5
QO  363.9    355.5    348.2    340.1   331.1    323.2    315.4    307.5    298.1    290.7
QO  283.3    276.0    267.0    258.3   251.4    242.9    234.7    228.1    220.1    213.8
QO  204.6    198.6    191.2    185.4   178.3    172.8    167.2    160.5    152.7    147.6
QO  141.4    136.6    131.9    127.1   122.4    116.8    112.6    108.4    104.2    100.0
QO   95.9     92.0     89.1     85.4    82.6     79.9     76.4     74.7     72.1     69.2
QO   66.8     64.8     62.8     60.5    58.3     56.4     54.6     52.8     51.1     49.3
QO   47.7     45.7     44.1     42.5    41.0     39.5     37.7     36.2     35.1     34.0
QO   32.6     31.3     30.0     28.8    27.8     27.1     26.1     24.9     24.0     23.1
QO   22.5     21.8     21.0     20.1    19.6     19.1     18.5     17.8     17.2     16.7
QO   16.3     15.9     15.6     15.2    14.9     14.6     14.2     13.9     13.7     13.4
QO   13.2     13.0     12.8     12.5    12.3     12.1     11.9     11.8     11.5     11.2
QO   10.9     10.7     10.5     10.4    10.2     10.0      9.8      9.5      9.3      9.2
QO    9.0      8.9      8.7      8.6     8.4      8.2      8.1      8.0      7.8      7.7
QO    7.5      7.4      7.3      7.1     7.0      6.9      6.8      6.6      6.5      6.3
QO    6.2      6.1      6.0      5.9     5.8      5.7      5.7      5.6      5.5      5.4
QO    5.3      5.2      5.1      5.0     5.0      4.9      4.8      4.8      4.7      4.7
QO    4.6      4.6      4.5      4.4     4.4      4.3      4.2      4.1      4.0      3.9
KK 12-10
KM Routing from node 12 to node 10
RD
RC   .070     .038     .070     3500  .00443
RX     20      120      126      139     165      172      208      248
RY  279.8    280.5    276.0    268.0   270.5    274.0    280.5    280.2
KK    SA8
KM Runoff from Sub-Area 8
```

Sample input for SCS Lumped Model - Continued

```
BA  0.46
PR     6      5      8
PW  .702   .072   .226
LG  1.20    .13   6.57  .1983
UD  1.05
KK 11-10
KM Routing from node 11 to node 10
RD
RC   .07   .038    .07   2850 .00542
RX    20    120    126    139    165    172    208    248
RY 279.8  280.5  276.0  268.0  270.5  274.0  280.5  280.2
KK   SA6
KM Runoff from Sub-Area 6
BA  1.29
PR     6      4     54      7     55      5
PW  .601   .090   .128   .012   .061   .108
LG  1.20    .13   6.57  .1983
UD  1.54
KK  C101
KM Combine Hydrographs at node 10
HC     3
KK  10-7
KM Routing from node 10 to node 7
RD
RC  .070   .038   .070   3650 .00315
RX    20    120    126    139    165    172    208    248
RY 279.8  280.5  276.0  268.0  270.5  274.0  280.5  280.2
KK   SA7
KM Runoff from Sub-Area 7
BA  0.63
PR    53      7     55     10
PW  .010   .574   .321   .095
LG  1.20    .13   6.57  .1983
UD  0.93
KK   9-8
KM Routing from node 9 to node 8
RD
RC  .080   .035   .080   2800 .00482
RX  4876   4926   4979   4996   5003   5021   5051   5126
RY 301.4  301.3  301.5  291.0  291.3  300.5  299.7  299.6
KK   SA5
KM Runoff from Sub-Area 5
BA  0.78
PR     4     50     53      7     54
PW  .051   .220   .146   .375   .208
LG  1.20    .13   6.57  .1983
UD  0.89
KK   C81
KM Combine Hydrographs at node 8
HC     2
KK   8-7
KM Routing from node 8 to node 7
RD
RC  .080   .035   .080   2800 .00482
RX  4876   4926   4979   4996   5003   5021   5051   5126
RY 301.4  301.3  301.5  291.0  291.3  300.5  299.7  299.6
KK GAGE4
KM Observed vs. Computed
IN     2 180CT81  2119
QO   0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
QO   0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
QO   0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
QO   0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
QO   0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
QO   0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
QO   0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
```

Sample input for SCS Lumped Model - Continued

```
QO    0.0     0.0     0.0     0.0     5.6    11.3    15.1    20.9    35.6    53.5
QO   66.5    77.6    90.2   102.9   115.7   128.8   142.9   158.2   171.9   183.8
QO  201.8   225.9   245.2   259.8   273.4   286.1   298.2   309.6   319.2   327.2
QO  335.1   340.7   343.9   347.2   347.2   347.2   347.2   346.5   345.2   343.8
QO  339.2   331.3   323.4   315.5   307.7   303.0   301.5   300.0   298.4   296.9
QO  294.0   289.7   285.3   280.9   276.6   272.2   267.9   263.5   258.1   252.7
QO  247.3   242.5   238.4   232.8   225.8   218.9   211.9   204.9   197.9   190.9
QO  184.0   177.3   170.6   163.9   157.2   150.5   143.8   138.6   133.3   128.1
QO  122.8   117.8   113.2   108.5   103.9    99.2    95.2    91.8    88.3    84.9
QO   81.5    78.1    74.7    71.3    68.8    66.3    63.9    61.4    58.9    56.5
QO   54.0    51.5    49.1    46.6    44.4    42.6    40.8    39.0    37.2    35.6
QO   34.5    33.3    32.1    30.9    29.9    29.1    28.4    27.6    26.9    26.1
QO   25.3    24.6    23.8    23.1    22.5    22.1    21.7    21.3    20.9    20.5
QO   20.1    19.7    19.3    18.9    18.5    18.1    17.7    17.3    16.9    16.5
QO   16.1    15.7    15.3    14.9    14.5    14.1    13.7    13.5    13.2    12.9
QO   12.6    12.4    12.1    11.8    11.5    11.3    11.0    10.7    10.4    10.2
QO    9.9     9.6     9.3     9.1     8.8     8.5     8.3     8.1     7.9     7.7
QO    7.5     7.3     7.1     7.0     6.8     6.6     6.4     6.2     6.0     5.8
QO    5.7     5.6     5.5     5.4     5.3     5.2     5.1     5.0     4.8     4.7
QO    4.6     4.5     4.4     4.3     4.2     4.2     4.1     4.1     4.0     4.0
QO    3.9     3.9     3.8     3.8     3.7     3.7     3.7     3.6     3.6     3.6
QO    3.6     3.5     3.5     3.5     3.5     3.4     3.4     3.4     3.3     3.3
QO    3.3     3.3     3.2     3.2     3.2     3.2     3.1     3.1     3.1     3.0
KK    C71
KM Combine Hydrographs at node 7
HC      2
KK GAGE3
KM Observed vs. Computed
IN      2 18OCT81    2119
QO    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
QO    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     2.8
QO    7.2     8.7     9.5    10.3    12.1    14.5    16.6    20.7    25.4    37.2
QO   60.9    92.9   145.8   199.3   253.4   302.2   349.7   394.5   435.3   485.8
QO  527.7   567.5   617.4   669.7   743.2   781.8   841.1   861.6   898.0   866.7
QO  956.9   995.5   984.4   956.9   984.4  1012.2  1005.6   973.4   988.5  1050.6
QO1042.2  1033.9  1025.5   956.9   946.1   935.2   913.9   935.2   978.9   946.1
QO  929.9   908.6   841.1   826.0   806.1   785.1   772.6   760.2   747.7   735.3
QO  725.6   718.6   705.9   692.2   678.6   660.8   638.9   621.8   604.7   592.3
QO  579.9   567.5   547.4   533.5   516.0   502.7   485.8   474.7   458.4   447.7
QO  435.3   424.9   414.6   401.3   388.0   376.5   368.5   362.2   354.4   340.5
QO  331.7   322.9   314.1   305.3   296.6   285.4   277.2   266.5   261.2   250.9
QO  244.5   235.8   228.4   218.9   210.7   203.9   197.0   189.2   184.9   177.4
QO  168.1   164.0   158.1   152.2   144.6   140.8   135.4   131.8   124.8   121.4
QO  118.0   113.1   108.2   105.0   100.4    97.3    92.9    90.0    88.1    85.8
QO   83.0    80.3    78.5    76.3    73.8    71.2    69.0    67.1    65.4    63.9
QO   62.3    58.1    56.6    55.2    53.7    51.6    50.0    49.0    47.5    45.5
QO   44.2    43.0    41.7    40.3    38.9    38.1    37.2    35.9    34.6    33.8
QO   33.0    31.9    31.0    30.2    29.4    28.7    28.0    27.4    26.8    26.0
QO   25.1    24.5    24.1    23.7    23.3    22.5    21.8    21.2    20.8    20.5
QO   20.1    19.6    19.1    18.8    18.5    18.2    17.9    17.6    17.3    17.0
QO   16.8    16.4    16.1    15.8    15.5    15.2    14.9    14.6    14.4    14.1
QO   13.9    13.7    13.6    13.4    13.2    13.1    12.9    12.7    12.6    12.4
QO   12.2    12.0    11.7    11.3    11.1    11.0    10.9    10.8    10.7    10.6
QO   10.5    10.4    10.3    10.2    10.0     9.9     9.7     9.5     9.4     9.2
KK    7-5
KM Routing from node 7 to node 5
RD
RC    .07    .038     .07    4070  .00381
RX   4856    4960    4972    4986    5014    5022    5040    5156
RY  262.5   264.0   257.5   252.5   253.3   256.5   264.8   263.7
KK    SA4
```

Sample input for SCS Lumped Model - Continued

```
KM Runoff for Sub-Area 4
BA  0.60
PR    52      53      50      14
PW  .458    .345    .035    .162
LG   0.6     .13    6.57   .1983
UD  0.80
KK   6-5
KM Routing from node 6 to node 5
RD
RC   .07    .038     .07    3400  .00750
RX  4856    4960    4972    4986    5014    5022    5040    5156
RY 262.5   264.0   257.5   252.5   253.3   256.5   264.8   263.7
PG     1                      10
IN     1 18OCT81    2119
PI 0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002
PI 0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002
PI 0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002
PI 0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002
PI 0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002
PI 0.002   0.002   0.002   0.002   0.005   0.005   0.005   0.005   0.001   0.001
PI 0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
PI 0.001   0.001   0.001   0.006   0.006   0.006   0.006   0.006   0.006   0.006
PI 0.006   0.006   0.006   0.006   0.039   0.039   0.039   0.039   0.039   0.039
PI 0.039   0.039   0.034   0.034   0.034   0.034   0.034   0.034   0.034   0.034
PI 0.000   0.000   0.000   0.018   0.018   0.018   0.018   0.007   0.007   0.007
PI 0.010   0.010   0.010   0.028   0.028   0.028   0.028   0.028   0.008   0.008
PI 0.008   0.008   0.008   0.022   0.022   0.022   0.022   0.022   0.022   0.051
PI 0.051   0.051   0.051   0.051   0.051   0.051   0.051   0.051   0.051   0.051
PI 0.051   0.051   0.051   0.051   0.047   0.047   0.047   0.015   0.015   0.015
PI 0.015   0.000   0.000   0.007   0.007   0.007   0.007   0.007   0.007   0.007
PI 0.007   0.007   0.007   0.007   0.007   0.007   0.007   0.007   0.005   0.005
PI 0.005   0.005   0.005   0.005   0.005   0.005   0.012   0.012   0.012   0.012
PI 0.012   0.012   0.012   0.012   0.012   0.012   0.012   0.012   0.012   0.011
PI 0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011
PI 0.050   0.004   0.004   0.004   0.004   0.004   0.004   0.004   0.004   0.004
PI 0.004
PG     2                      11
IN     1 18OCT81    2119
PI 0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
PI 0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
PI 0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
PI 0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
PI 0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
PI 0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
PI 0.003   0.003   0.003   0.003   0.027   0.027   0.027   0.004   0.004   0.004
PI 0.004   0.004   0.027   0.027   0.027   0.027   0.027   0.027   0.034   0.034
PI 0.034   0.034   0.034   0.034   0.034   0.034   0.034   0.034   0.034   0.034
PI 0.034   0.034   0.000   0.000   0.000   0.008   0.008   0.008   0.008   0.008
PI 0.008   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021   0.021
PI 0.022   0.022   0.022   0.022   0.022   0.022   0.022   0.022   0.022   0.022
PI 0.022   0.022   0.022   0.022   0.054   0.054   0.054   0.054   0.054   0.054
PI 0.054   0.054   0.054   0.033   0.033   0.033   0.033   0.033   0.033   0.033
PI 0.033   0.013   0.013   0.013   0.013   0.013   0.013   0.013   0.013   0.013
PI 0.013   0.000   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009
PI 0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009
PI 0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009
PI 0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009   0.009
PI 0.009   0.009   0.009   0.009   0.009   0.009   0.004   0.004   0.004   0.004
PI 0.004   0.004   0.004   0.004   0.004   0.004   0.004   0.004   0.004   0.004
PI 0.004
KK   SA3
KM Runoff from Sub-Area 3
BA  0.90
PR     2      13      14      50       4       6
PW  .389    .244    .164    .071    .114    .018
LG   0.6     .13    6.57   .1983
```

Sample input for SCS Lumped Model - Continued

```
UD  0.97
KK   C51
KM Combine Hydrographs at node 5
HC     3
KK   5-3
KM Routing from node 5 to node 3
RD
RC   .07     .038     .07    4144  .00193
RX  4856     4960    4972    4986    5014    5022    5040    5156
RY 262.5    264.0   257.5   252.5   253.3   256.5   264.8   263.7
KK   SA2
KM Runoff from Sub-Area 2
BA  0.60
PR    51       52      14      13       2
PW  .485     .288    .048    .157    .022
LG   0.6      .13    6.57   .1983
UD  1.11
KK   4-3
KM Routing from node 4 to node 3
RD
RC   .07     .038     .07    6345  .00750
RX  4856     4960    4972    4986    5014    5022    5040    5156
RY 262.5    264.0   257.5   252.5   253.3   256.5   264.8   263.7
KK   C31
KM Combine hydrographs at node 3
HC     2
KK GAGE2
KM Observed vs. Computed
IN     2 18OCT81    2119
QO   0.6      0.6     0.6     0.6     0.6     0.6     0.6     0.6     0.6     0.6
QO   0.6      0.6     0.6     0.6     0.6     0.6     0.6     0.6     0.6     0.6
QO   0.7      0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7
QO   0.7      0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7
QO   0.7      0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.7     0.8
QO   0.9      1.0     1.0     1.0     1.0     1.0     1.0     1.0     1.0     1.0
QO   1.0      1.0     1.0     1.0     1.0     1.0     1.0     4.3     4.6     6.1
QO   8.9     13.2    18.1    22.4    26.5    30.2    34.2    40.3    45.2    51.2
QO  58.7     69.3    81.3    95.1   112.2   129.1   147.4   165.0   190.3   232.1
QO 299.4    375.9   447.6   531.1   610.6   699.2   778.6   864.7   948.2  1022.5
QO1083.6   1129.9  1188.3  1231.7  1270.4  1304.1  1332.3  1372.5  1407.4  1423.1
QO1442.8   1460.7  1472.7  1484.7  1496.7  1527.1  1527.1  1527.1  1527.1  1527.1
QO1527.1   1527.1  1527.1  1527.1  1541.4  1533.2  1521.0  1502.8  1495.5  1488.3
QO1472.7   1456.2  1447.3  1439.9  1433.9  1427.4  1420.4  1413.3  1375.4  1349.5
QO1332.3   1301.2  1270.5  1220.8  1213.5  1201.8  1172.2  1140.4  1116.0  1093.5
QO1073.0   1037.5  1002.1   973.8   948.2   918.7   884.4   861.1   838.1   813.0
QO 788.4    768.9   749.8   712.3   694.3   676.3   658.3   631.9   620.5   604.3
QO 581.4    565.0   545.0   521.4   502.4   487.3   468.8   461.6   450.8   436.7
QO 421.1    409.2   399.1   382.7   369.9   357.1   350.9   337.2   326.7   314.9
QO 303.4    294.9   286.5   277.0   267.6   258.4   249.3   244.3   234.3   227.0
QO 222.2    216.3   209.4   202.4   196.7   191.2   185.7   180.4   174.1   169.6
QO 166.9    160.8   157.0   153.3   149.5   145.7   141.9   138.2   134.4   131.2
QO 128.5    126.3   124.6   122.1   118.7   115.4   112.0   109.9   107.2   104.1
QO 101.8     99.5    97.5    95.5    93.5    90.6    88.4    86.3    84.9    83.5
QO  81.7     79.9    78.1    75.5    73.4    71.9    70.4    69.2    67.9    66.4
QO  64.8     63.3    61.7    60.2    58.6    57.1    55.5    53.9    52.6    51.8
QO  50.9     50.0    49.0    48.0    47.0    46.0    45.0    44.0    43.0    42.1
QO  41.3     40.6    39.8    38.9    38.0    37.1    36.3    35.6    35.0    34.5
QO  34.0     33.6    33.1    32.6    32.1    31.7    31.5    31.2    31.0    30.8
QO  30.6     30.3    30.1    29.7    29.2    28.7    28.3    27.8    27.5    27.3
KK   3-2
KM Routing from node 3 to node 2
RD
RC  .070     .037    .070    5743  .00293
RX  4900     4931    4961    4985    5000    5039    5070    5100
RY 240.0    236.0   234.0   223.0   220.0   234.0   236.0   240.0
KK   SA1
```

Sample input for SCS Lumped Model - Continued

```
KM Runoff from Sub-Area 1
BA  1.44
PR     1         2        51
PW  .375      .271      .354
LG   0.6       .13      6.57     .1983
UD  1.20
KK   C21
KM Combine hydrographs at node 2
HC     2
KK   2-1
KM Routing from node 2 to node 1
RD
RC  .070      .037      .070      5743    .00155
RX  4900      4931      4961      4985      5000      5039      5070      5100
RY 240.0     236.0     234.0     223.0     220.0     234.0     236.0     240.0
KK GAGE1
KM Observed vs. Computed
IN     2 18OCT81     2119
QO   1.0       1.0       1.0       1.0       1.0       1.1       1.1       1.1       1.1       1.1
QO   1.1       1.1       1.1       1.1       1.1       1.1       1.1       1.1       1.1       1.2
QO   1.2       1.2       1.2       1.2       1.2       1.2       1.2       1.2       1.2       1.2
QO   1.2       1.2       1.2       1.3       1.3       1.3       1.3       1.3       1.4       1.4
QO   1.4       1.9       2.3       2.7       3.2       3.6       4.1       4.5       4.7       4.7
QO   4.7       4.7       4.7       4.7       5.1       5.9       7.5       9.1       9.9      10.7
QO  11.5      12.3      13.1      13.9      14.7      15.5      17.0      18.4      19.8      21.2
QO  22.7      25.8      29.0      32.6      36.7      40.8      45.9      50.9      56.0      61.1
QO  66.2      67.5      68.7      69.9      71.2      70.4      69.7      69.0      68.3      67.6
QO  66.9      66.2      66.2      66.2      70.0      73.7      87.8     101.9     139.1     176.4
QO 225.4     274.5     354.9     435.3     477.6     519.9     577.7     638.9     693.4     747.9
QO 807.3     866.7     906.4     946.0     995.8    1045.6    1083.7    1122.6    1154.4    1186.2
QO1210.6    1235.0    1259.8    1284.9    1301.8    1318.7    1334.7    1350.7    1364.4    1376.0
QO1387.6    1393.4    1399.3    1405.1    1405.1    1405.1    1402.8    1400.4    1398.1    1395.7
QO1393.4    1386.5    1379.5    1372.6    1365.6    1358.7    1341.6    1324.6    1307.6    1290.7
QO1273.7    1287.1    1300.7    1314.3    1327.9    1341.4    1287.4    1234.5    1182.7    1130.9
QO1081.1    1065.1    1049.0    1032.9    1016.8    1000.7     982.2     963.8     945.4     926.9
QO 908.5     882.3     857.1     831.9     806.7     781.5     757.4     734.4     711.3     688.3
QO 665.2     646.9     628.5     610.9     593.2     575.6     560.3     545.0     530.1     515.3
QO 500.8     487.5     474.2     460.9     448.1     435.3     424.7     414.1     403.4     393.1
QO 383.0     373.2     363.4     353.6     343.8     334.4     326.9     319.4     311.9     304.3
QO 296.8     289.3     282.3     275.3     268.2     261.2     254.3     247.6     240.9     234.3
QO 227.6     221.0     214.3     208.0     201.9     195.8     191.2     186.6     182.2     177.9
QO 173.5     169.1     164.8     160.4     156.4     152.2     149.0     145.7     142.5     139.5
QO 136.4     133.4     130.3     127.3     124.2     121.3     118.9     116.4     113.9     111.4
QO 109.0     106.6     104.3     102.0      99.7      97.3      95.3      94.2      92.7      91.1
QO  89.6      88.0      86.5      85.1      83.6      82.1      80.7      79.2      77.8      76.4
QO  75.0      73.6      72.3      71.0      69.7      68.4      67.1      65.7      64.4      63.2
QO  62.0      60.8      59.5      58.3      57.1      55.9      54.9      54.0      53.0      52.0
QO  51.1      50.2      49.3      48.3      47.4      46.5      45.7      45.0      44.2      43.5
ZW   A=DEC    B=GOODWIN    C=FLOW    F=CAL
ZZ
```

Sample input for SCS Lumped Model - Continued

```
47    75    126.83      3      0.
5.    5760    2532      12      12
44    3    0.01      1500.    23.63    6.05    0.037
1     3
19     16
1
1
17          12     <---- change when you change the time step
4.5   43.5
15.5  26.5
33.5  20.5
45.5  16.5
41.5  9.5
44.5  25.5
58.5  11.5
57.5  16.5
62.5  14.5
19.5  26.5
28.5  26.5
33.5  23.5
22.5  34.5
30.5  33.5
37.5  29.5
39.5  18.5
52.5  19.5
0.07
0.1
0.06
9.44444E-7  0.0889  0.25
1.4E-6  0.1668  0.25
2.6E-6  0.1101  0.25
1       5
28  15
20  33
21  34
16  45
11  60
```

Sample **DATA1** input file for CASC2D

```
   0.094   0.171   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
0.000   0.000   0.000   0.000   0.000   0.046
   0.094   0.171   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
0.240   0.000   0.000   0.000   0.000   0.046
   0.094   0.171   0.000   0.067   0.000   0.000   0.000   0.000   0.000   0.000   0.000
0.240   0.000   0.000   0.000   0.960   0.046
   0.094   0.171   0.050   0.067   0.000   0.000   0.240   0.000   0.000   0.000   0.000
0.240   0.000   0.000   0.000   0.960   0.046
   0.094   0.171   0.050   0.067   0.000   0.000   0.240   0.000   0.000   0.000   0.000
0.240   0.000   0.000   0.000   0.960   0.046
   0.094   0.171   0.050   0.067   0.000   0.000   0.240   0.000   0.000   0.000   0.000
0.240   0.000   0.000   0.000   0.960   0.046
   0.094   0.171   0.050   0.067   0.000   0.000   0.240   0.000   0.000   0.000   0.000
0.240   0.000   0.000   0.000   0.960   0.046
   0.094   0.171   0.050   0.067   0.000   0.000   0.240   0.000   0.000   0.000   0.000
2.400   0.000   0.000   0.000   0.960   0.046
   0.094   0.171   0.050   0.067   0.000   0.000   0.240   0.000   0.000   0.000   0.000
2.400   0.000   0.000   0.000   0.030   0.046
   0.094   0.171   0.050   0.067   0.000   0.000   0.240   0.000   0.000   0.000   0.000
0.086   0.000   0.000   0.000   0.030   0.046
   0.094   0.171   0.050   0.067   0.000   0.857   0.240   0.000   0.000   0.000   0.000
0.086   0.000   1.000   0.000   0.030   0.046
   0.094   0.171   0.050   0.067   0.000   0.857   0.240   0.000   0.000   1.400   0.000
0.086   0.000   1.000   0.000   0.030   0.046
   0.094   0.171   0.050   0.840   0.450   0.857   0.240   1.200   0.000   1.400   1.200
0.086   1.050   1.000   0.000   0.030   0.046
   0.094   0.171   0.050   0.840   0.450   0.857   0.240   1.200   0.000   1.400   1.200
0.086   1.050   1.000   0.000   0.030   0.046
   0.094   0.171   0.050   0.840   0.450   0.857   0.240   1.200   0.000   0.060   1.200
0.086   1.050   1.000   0.000   0.030   1.200
   0.094   0.171   0.050   0.840   0.450   0.857   0.240   1.200   0.000   0.060   1.200
0.086   1.050   1.000   0.400   0.030   1.200
   0.094   0.171   1.200   0.840   0.450   0.857   0.240   1.200   0.000   0.060   1.200
0.039   0.360   0.015   0.400   0.030   1.200
   0.094   0.171   1.200   0.041   0.450   0.016   0.240   0.016   0.000   0.060   0.015
0.039   0.360   0.015   0.400   0.030   1.200
   0.094   0.171   1.200   0.041   0.450   0.016   0.240   0.016   0.000   0.060   0.015
0.039   0.360   0.015   0.400   0.030   1.200
   0.094   0.171   1.200   0.041   0.450   0.016   0.400   0.016   0.000   0.060   0.015
0.039   0.360   0.015   0.400   0.030   0.032
   0.094   0.171   0.049   0.041   0.018   0.016   0.400   0.016   0.000   0.060   0.015
0.039   0.360   0.015   0.400   0.030   0.032
   0.094   0.171   0.049   0.041   0.018   0.016   0.400   0.016   0.000   0.060   0.015
0.039   0.017   0.015   0.019   0.030   0.032
   0.094   0.171   0.049   0.041   0.018   0.016   0.400   0.016   0.000   0.060   0.015
0.039   0.017   0.015   0.019   0.030   0.032
   0.094   0.171   0.049   0.041   0.018   0.016   0.400   0.016   0.300   0.060   0.015
0.039   0.017   0.015   0.019   0.030   0.032
   0.094   0.171   0.049   0.041   0.018   0.016   0.400   0.016   0.300   0.060   0.015
0.039   0.017   0.015   0.019   0.030   0.032
   0.094   0.171   0.049   0.041   0.018   0.016   0.040   0.016   1.800   0.060   0.015
0.039   0.017   0.015   0.019   0.030   0.032
   0.094   0.171   0.049   0.041   0.018   0.016   0.040   0.016   1.800   0.060   0.015
0.039   0.017   0.015   0.019   0.030   0.032
   0.094   0.171   0.049   0.041   0.018   0.016   0.040   0.016   1.800   0.060   0.015
0.039   0.017   0.015   0.019   0.030   0.032
   0.094   0.171   0.049   0.041   0.018   0.016   0.040   0.016   0.032   0.060   0.015
0.039   0.017   0.015   0.019   0.030   0.032
   0.094   0.171   0.049   0.041   0.018   0.016   0.040   0.016   0.032   0.060   0.015
0.039   0.017   0.015   0.019   0.030   0.032
   0.094   0.171   0.049   0.041   0.018   0.016   0.040   0.016   0.032   0.060   0.015
0.039   0.017   0.015   0.019   0.030   0.032
   0.094   0.171   0.049   0.041   0.018   0.016   0.040   0.016   0.032   0.060   0.015
0.039   0.017   0.015   0.019   0.030   0.032
   0.094   0.171   0.049   0.041   0.018   0.016   0.040   0.016   0.032   0.060   0.015
0.039   0.017   0.015   0.019   0.030   0.032
```

Sample **RAIN.DAT** input file for CASC2D

0.094	0.171	0.049	0.041	0.018	0.016	0.040	0.016	0.032	0.060	0.015
0.039	0.017	0.015	0.019	0.030	0.032					
0.094	0.171	0.049	0.041	0.018	0.016	0.040	0.016	0.032	0.060	0.015
0.039	0.017	0.015	0.019	0.030	0.032					
0.094	0.171	0.049	0.041	0.018	0.016	0.040	0.016	0.032	0.060	0.015
0.039	0.017	0.015	0.019	0.030	0.032					
0.094	0.171	0.049	0.041	0.018	0.016	0.040	0.016	0.032	0.060	0.015
0.039	0.017	0.015	0.019	0.030	0.032					
0.094	0.171	0.049	0.041	0.018	0.016	0.040	0.016	0.032	0.060	0.015
0.039	0.017	0.015	0.019	0.030	0.032					
0.094	0.171	0.049	0.041	0.018	0.016	0.040	0.016	0.032	0.060	0.015
0.039	0.017	0.015	0.019	0.030	0.032					
0.094	0.171	0.049	0.041	0.018	0.016	0.040	0.016	0.032	0.060	0.015
0.039	0.017	0.015	0.019	0.030	0.032					
0.094	0.171	0.049	0.041	0.018	0.016	0.040	0.016	0.032	0.060	0.015
0.039	0.017	0.015	0.019	0.030	0.032					
0.094	0.171	0.049	0.041	0.018	0.016	0.040	0.016	0.032	0.060	0.015
0.039	0.017	0.015	0.019	0.030	0.032					
0.094	0.171	0.049	0.041	0.018	0.016	0.040	0.016	0.032	0.060	0.015
0.039	0.017	0.015	0.019	0.030	0.032					
0.094	0.171	0.049	0.041	0.018	0.016	0.040	0.016	0.032	0.060	0.015
0.039	0.017	0.015	0.019	0.030	0.032					
0.094	0.171	0.049	0.041	0.018	0.016	0.040	0.016	0.032	0.060	0.015
0.039	0.017	0.015	0.019	0.030	0.032					
0.094	0.171	0.049	0.041	0.018	0.016	0.040	0.016	0.032	0.060	0.015
0.039	0.017	0.015	0.019	0.030	0.032					
0.094	0.171	0.049	0.240	0.018	0.016	0.040	0.016	0.032	0.060	0.015
0.039	0.017	0.015	0.019	0.030	0.032					
0.094	0.171	0.049	0.240	0.018	0.016	0.040	0.016	0.032	0.060	0.015
1.200	0.017	0.015	0.019	0.030	0.032					
0.094	0.171	0.049	0.240	0.018	0.016	0.040	0.016	0.032	0.060	0.015
1.200	0.017	0.015	0.019	3.200	0.032					
0.094	0.171	0.049	0.240	0.018	0.016	0.040	0.016	0.032	0.060	0.015
1.200	0.017	0.015	0.019	3.200	0.032					
0.094	0.171	0.049	0.240	0.018	0.016	0.040	0.016	0.032	0.060	0.015
1.200	0.017	0.015	0.019	3.200	0.032					
0.094	0.171	0.049	1.527	0.018	0.016	0.040	0.016	0.032	0.060	0.015
1.200	0.017	0.015	0.019	0.857	0.032					
0.094	0.171	0.049	1.527	0.018	0.016	0.040	0.016	0.032	0.060	0.015
1.200	0.017	0.015	0.133	0.857	0.032					
0.094	0.171	0.049	1.527	0.018	0.016	0.040	0.016	0.032	0.060	0.015
1.200	0.017	0.015	0.133	0.857	0.032					
0.300	0.171	0.049	1.527	1.600	0.375	0.040	1.855	0.032	0.720	0.015
1.200	0.017	0.015	0.133	0.857	0.032					
0.300	0.171	0.049	1.527	1.600	0.375	1.600	1.855	0.032	0.720	0.015
1.200	0.017	0.015	0.133	0.857	0.032					
0.300	0.171	0.049	1.527	1.600	0.375	1.600	1.855	0.032	0.720	2.000
1.200	0.017	0.960	0.133	0.857	0.032					
0.300	0.171	1.333	1.527	1.600	0.375	1.600	1.855	0.032	0.720	2.000
0.171	1.000	0.960	0.133	0.857	1.431					
0.040	0.171	1.333	1.527	1.600	0.375	1.600	1.855	0.032	0.720	2.000
0.171	1.000	0.960	0.133	0.360	1.431					
0.040	0.171	1.333	1.527	1.600	0.375	1.600	1.855	0.032	0.720	0.800
0.171	1.000	0.960	0.133	0.360	1.431					
0.040	0.171	1.333	1.527	1.600	0.375	1.600	1.855	0.032	0.720	0.800
0.171	0.500	0.960	0.133	0.360	1.431					
0.040	0.171	1.333	1.527	1.600	0.375	1.091	1.855	0.032	0.720	0.800
0.171	0.500	0.800	0.857	0.360	1.431					
0.040	0.171	1.333	0.785	1.600	0.150	1.091	1.855	0.032	0.720	0.800
0.171	0.500	0.800	0.857	0.360	1.431					
0.040	0.171	1.333	0.785	1.600	0.150	1.091	1.855	0.032	0.720	0.800
0.171	0.500	0.800	0.857	1.600	1.431					
0.040	1.600	1.333	0.785	1.600	0.150	1.091	1.855	0.032	0.171	0.800
1.200	0.500	0.257	0.857	1.600	1.431					
0.040	1.600	1.333	0.785	1.600	0.150	1.091	0.120	1.000	0.171	0.086
1.200	0.500	0.257	0.857	1.600	1.431					

Sample **RAIN.DAT** input file for CASC2D - Continued

```
   0.040   1.600   0.200   0.785   1.080   0.150   1.091   0.120   1.000   0.171   0.086
 1.200   0.100   0.257   0.857   1.650   1.431
   0.040   0.240   0.200   0.785   1.080   0.150   1.091   0.120   1.000   0.171   0.086
 1.200   0.100   0.257   0.857   1.650   1.431
   0.040   0.240   0.200   0.785   1.080   0.150   1.091   0.120   3.000   0.171   0.086
 1.638   0.100   0.257   0.200   1.650   1.431
   0.040   0.240   0.200   0.785   1.080   0.150   1.091   0.120   3.000   0.171   0.086
 1.638   0.100   0.257   0.200   1.650   1.431
   0.040   0.240   0.200   0.785   1.080   0.450   1.091   2.100   3.000   0.171   0.086
 1.638   0.100   0.257   0.200   1.650   0.150
   0.040   0.240   0.200   0.785   1.080   0.450   1.091   2.100   3.000   1.050   0.086
 1.638   0.100   0.300   1.029   1.650   0.150
   0.040   1.600   0.780   0.785   1.080   0.450   1.333   2.100   1.371   1.050   0.600
 1.638   1.800   0.300   1.029   1.650   0.150
   0.382   1.600   0.780   0.785   1.080   0.450   1.333   2.100   1.371   1.050   0.600
 1.638   1.800   0.300   1.029   1.650   0.150
   0.382   1.600   0.780   0.785   1.080   0.450   1.333   0.600   1.371   1.050   0.600
 1.638   0.400   0.300   1.029   1.650   1.920
   0.382   1.600   0.780   1.800   1.080   0.450   1.333   0.600   1.371   0.360   0.600
 1.638   0.400   0.900   1.029   1.650   1.920
   0.382   1.600   0.780   1.800   1.080   0.450   1.333   0.600   1.371   0.360   0.600
 1.638   0.400   0.900   1.029   1.650   1.920
   0.382   1.600   0.780   1.800   1.080   0.450   1.333   0.600   1.371   0.360   0.600
 1.638   0.686   0.900   1.029   1.650   1.920
   0.382   2.057   0.780   1.800   1.080   0.450   1.333   0.600   1.371   0.360   0.600
 1.638   0.686   0.900   1.100   1.650   1.920
   0.382   2.057   0.780   1.800   1.080   0.450   1.333   0.600   0.480   0.360   0.600
 1.638   0.686   0.900   1.100   1.650   0.400
   0.382   2.057   0.780   1.800   1.080   0.450   1.333   0.600   0.480   2.047   2.133
 1.638   0.686   0.900   1.100   1.650   0.400
   0.382   2.057   0.780   1.800   4.200   0.450   1.364   1.958   0.480   2.047   2.133
 1.638   0.686   0.900   1.100   1.650   0.400
   0.382   2.057   2.550   1.800   0.900   1.933   1.364   1.958   0.480   2.047   2.133
 1.638   0.686   0.900   1.100   1.800   1.414
   0.382   2.057   2.550   1.800   0.900   1.933   1.364   1.958   0.480   2.047   2.133
 1.638   0.686   2.850   1.100   1.800   1.414
   2.325   2.057   2.550   1.800   0.900   1.933   1.364   1.958   3.000   2.047   2.133
 1.638   2.143   2.850   1.629   1.800   1.414
   2.325   2.057   2.550   1.800   0.900   1.933   1.364   1.958   3.000   2.047   2.133
 1.638   2.143   2.850   1.629   1.800   1.414
   2.325   2.057   2.550   1.800   0.900   1.933   1.364   1.958   0.800   2.047   2.133
 1.638   2.143   2.850   1.629   1.800   1.414
   2.325   2.057   2.550   2.229   0.900   1.933   1.364   1.958   0.800   2.047   2.133
 1.638   2.143   2.850   1.629   1.800   1.414
   2.325   2.057   2.550   2.229   2.340   1.933   1.364   1.958   0.800   2.047   2.133
 1.638   2.143   2.850   1.629   0.429   1.414
   2.325   2.057   2.550   2.229   2.340   1.933   1.364   1.958   0.600   2.047   2.133
 1.638   2.143   2.850   1.629   0.429   1.414
   2.325   2.057   2.550   2.229   2.340   1.933   1.364   1.958   0.600   2.047   2.133
 1.638   2.143   2.850   1.629   0.429   1.414
   2.325   2.057   2.550   2.229   2.340   2.743   1.364   1.958   0.600   2.047   2.133
 1.638   3.400   1.200   2.700   0.429   1.414
   2.025   0.000   2.550   2.229   2.340   2.743   2.400   1.958   1.500   2.047   2.133
 1.638   3.400   1.200   2.700   0.429   1.414
   2.025   0.000   2.550   2.229   2.340   2.743   2.400   1.958   1.500   2.047   2.133
 1.638   3.400   1.200   1.950   0.429   1.414
   2.025   0.000   0.975   0.000   2.340   2.743   2.400   1.958   1.500   2.047   2.133
 0.000   2.100   1.200   1.950   0.429   1.414
   2.025   0.500   0.975   0.000   2.340   2.743   2.400   1.958   1.500   2.047   2.133
 0.000   2.100   1.200   1.950   0.700   1.414
   2.025   0.500   0.975   0.000   2.340   2.743   2.400   1.958   1.500   2.047   2.133
 0.000   2.000   1.200   1.950   0.700   2.175
   2.025   0.500   0.975   0.000   2.340   2.743   2.400   1.958   1.500   0.120   2.133
 1.500   2.000   1.200   2.100   0.700   2.175
   2.025   0.500   0.975   0.000   0.300   0.150   2.400   1.958   3.840   0.120   0.200
 1.500   2.000   1.200   2.100   0.700   2.175
```

Sample **RAIN.DAT** input file for CASC2D - Continued

```
  2.025   0.500   0.975   0.600   0.300   0.150   2.400   1.958   3.840   0.120   0.200
0.920   0.171   1.200   2.100   0.700   2.175
  0.000   0.500   0.975   0.600   0.300   0.150   2.400   0.240   3.840   0.120   0.200
0.920   0.171   0.000   2.100   0.700   2.175
  0.000   1.267   0.975   0.600   0.300   0.150   0.300   0.240   3.840   0.120   0.200
0.920   0.171   0.000   0.100   1.100   2.175
  0.000   1.267   0.000   0.600   0.300   0.969   0.300   0.240   3.840   0.900   0.200
0.920   0.171   0.000   0.100   1.100   2.175
  1.050   1.267   0.000   0.947   0.300   0.969   0.300   0.240   1.560   0.900   0.200
0.920   0.171   1.000   0.100   1.100   2.175
  1.050   1.267   0.000   0.947   0.300   0.969   0.300   0.240   1.560   1.050   0.500
0.920   0.171   1.000   0.100   1.100   0.257
  1.050   1.267   0.000   0.947   0.300   0.969   0.300   1.200   1.560   1.050   0.500
0.920   0.171   1.000   0.100   1.100   0.257
  1.050   1.267   0.000   0.947   0.300   0.969   0.300   1.200   1.560   1.050   0.500
0.920   2.400   0.150   0.100   1.100   0.257
  0.400   1.267   1.150   0.947   0.300   0.969   1.100   1.200   1.560   1.050   0.500
0.920   0.300   0.150   0.600   0.986   0.257
  0.400   1.267   1.150   0.947   0.300   0.969   1.100   1.200   0.400   1.050   0.500
0.920   0.300   0.150   0.600   0.986   0.257
  0.400   1.267   1.150   0.947   0.300   0.969   1.100   1.200   0.400   1.050   0.500
0.920   0.300   0.150   0.600   0.986   0.257
  0.600   1.329   1.150   0.947   1.855   0.969   1.100   1.200   0.400   1.050   1.700
0.920   0.300   1.900   0.200   0.986   0.257
  0.600   1.329   1.150   0.947   1.855   0.969   1.100   1.200   0.120   1.050   1.700
0.920   1.440   1.900   0.200   0.986   0.900
  0.600   1.329   1.150   0.947   1.855   0.969   1.100   1.200   0.120   1.050   1.700
0.920   1.440   1.900   0.200   0.986   0.900
  1.680   1.329   1.150   0.947   1.855   0.969   1.100   1.200   0.120   1.050   1.700
0.920   1.440   1.900   0.720   0.986   0.300
  1.680   1.329   1.150   0.947   1.855   0.969   1.100   1.200   0.120   1.050   1.700
1.440   1.440   1.900   0.720   0.986   0.300
  1.680   1.329   1.150   0.947   1.855   0.686   1.100   1.200   0.120   1.050   1.700
1.440   1.440   1.900   0.720   0.986   1.269
  1.680   1.329   1.150   0.947   1.855   0.686   1.100   1.200   0.400   0.600   1.926
1.440   1.400   0.525   0.720   0.986   1.269
  1.680   1.329   1.150   0.947   1.855   0.686   1.100   1.777   0.400   0.600   1.926
1.440   1.400   0.525   0.720   0.986   1.269
  0.480   1.329   1.150   0.947   1.855   0.686   1.100   1.777   0.400   0.600   1.926
1.440   1.400   0.525   7.200   0.986   1.269
  0.480   1.329   1.200   0.947   1.855   0.686   1.029   1.777   0.400   0.600   1.926
1.440   0.600   0.525   0.686   0.986   1.269
  0.480   1.329   1.200   0.947   1.855   0.686   1.029   1.777   0.400   0.600   1.926
1.440   0.600   0.525   0.686   0.986   1.269
  0.480   1.329   1.200   0.947   1.855   0.686   1.029   1.777   0.400   0.600   1.926
1.440   0.600   0.525   0.686   3.000   1.269
  0.480   1.329   1.200   2.400   1.855   1.500   1.029   1.777   2.520   0.600   1.926
1.440   0.600   0.525   0.686   3.000   1.269
  1.300   1.329   1.200   2.400   1.855   1.500   1.029   1.777   2.520   0.600   1.926
1.440   0.600   0.525   0.686   3.000   1.269
  1.300   3.267   1.200   2.400   1.855   1.500   1.029   1.777   2.520   2.463   1.926
3.075   0.600   1.500   0.686   3.000   1.269
  1.300   3.267   1.200   2.400   1.855   1.500   1.029   1.777   2.520   2.463   1.926
3.075   1.680   1.500   0.686   3.000   1.269
  1.300   3.267   1.200   2.400   1.855   2.509   1.029   1.777   2.520   2.463   1.926
3.075   1.680   1.500   1.000   3.000   1.269
  1.300   3.267   1.200   2.400   1.855   2.509   1.029   1.777   0.667   2.463   1.926
3.075   1.680   1.500   1.000   3.000   1.269
  1.300   3.267   1.200   2.400   1.855   2.509   1.029   1.777   0.667   2.463   1.926
3.075   1.680   1.500   1.000   3.000   1.269
  3.040   3.267   1.200   2.400   1.855   2.509   1.029   1.777   0.667   2.463   1.926
3.075   1.680   1.500   1.000   2.100   1.269
  3.040   3.267   1.200   2.400   1.855   2.509   1.029   1.777   0.667   2.463   1.926
3.075   2.000   3.218   1.000   2.100   1.269
  3.040   3.267   1.200   3.720   1.855   2.509   1.029   1.777   0.667   2.463   1.926
3.075   2.000   3.218   1.000   2.100   1.269
```

Sample **RAIN.DAT** input file for CASC2D - Continued

```
 3.040  3.267  1.200  3.720  2.400  2.509  1.029  1.777  0.667  2.463  1.926
2.571  2.000  3.218  3.000  2.100  1.269
 3.040  1.950  2.914  3.720  2.400  2.509  4.133  1.777  0.6 #'  2.463  1.926
2.571  2.000  3.218  3.000  2.100  1.269
 3.040  1.950  2.914  3.720  2.400  2.509  4.133  1.777  0.667  2.463  1.926
2.571  2.000  3.218  0.600  2.100  1.269
 3.040  1.950  2.914  3.720  2.400  2.509  4.133  1.777  0.667  2.463  2.200
2.571  2.000  3.218  0.600  2.100  1.269
 3.040  1.950  2.914  1.714  2.400  2.509  4.133  1.777  1.680  2.463  2.200
2.571  6.200  3.218  4.000  2.100  1.269
 3.040  1.950  2.914  1.714  2.400  2.700  4.133  1.777  1.680  2.463  2.200
2.571  6.200  3.218  4.000  0.643  1.269
 3.040  1.950  2.914  1.714  2.400  2.700  4.133  1.777  1.680  2.463  2.200
2.571  6.200  3.218  4.000  0.643  1.269
 3.040  1.950  2.914  1.714  2.400  2.700  4.133  1.777  1.680  2.463  2.200
0.764  1.950  3.218  3.000  0.643  1.269
 3.040  1.950  2.127  1.714  2.400  2.700  4.133  1.777  1.680  2.463  2.200
0.764  1.950  3.218  3.000  0.643  1.269
 3.040  0.780  2.127  1.714  2.400  2.700  4.133  1.777  2.700  2.463  2.200
0.764  1.950  2.100  3.000  0.643  2.914
 3.040  0.780  2.127  1.714  0.000  2.700  0.000  1.777  2.700  2.463  2.200
0.764  1.950  2.100  3.000  0.643  2.914
 3.040  0.780  2.127  0.600  0.000  2.700  0.000  0.975  2.700  1.050  2.200
0.764  1.800  2.100  2.000  0.643  2.914
 2.800  0.780  2.127  0.600  0.000  2.700  0.000  0.975  2.700  1.050  0.857
0.764  1.800  2.100  2.000  0.643  2.914
 2.800  0.780  2.127  0.600  0.000  2.400  0.000  0.975  4.800  1.050  0.857
0.764  1.800  1.000  2.000  0.643  2.914
 2.800  0.780  2.127  0.600  0.000  2.400  0.000  0.975  4.800  1.050  0.857
0.764  1.800  1.000  1.400  0.643  2.914
 0.900  0.780  2.127  0.600  0.000  2.400  0.000  0.975  2.200  1.050  0.857
0.764  1.800  1.000  1.400  0.643  2.914
 0.900  0.780  2.127  0.600  0.000  2.400  0.000  0.975  2.200  1.050  0.857
0.764  1.800  1.000  1.400  0.643  5.400
 0.900  0.780  2.127  0.600  0.000  2.400  0.000  0.975  2.200  1.050  0.857
0.764  1.800  1.000  1.500  0.643  5.400
 0.900  0.780  2.127  0.000  0.000  3.600  0.000  0.975  2.400  1.050  0.857
4.800  0.000  1.000  1.500  0.643  5.400
 0.000  0.000  0.000  0.338  0.189  4.800  1.500  0.000  3.000  1.200  0.600
0.109  0.000  0.000  0.420  0.000  0.000
 0.000  0.545  0.525  0.338  0.189  0.360  1.500  0.369  1.200  1.200  0.514
0.109  0.771  0.700  0.420  0.356  2.400
 0.400  0.545  0.525  0.338  0.189  0.360  1.200  0.369  1.200  0.429  0.514
0.109  0.771  0.700  0.420  0.356  2.400
 0.400  0.545  0.525  0.338  0.189  0.360  1.200  0.369  1.200  0.429  0.514
0.109  0.771  0.700  0.420  0.356  2.400
 0.400  0.545  0.525  0.338  0.189  0.360  0.309  0.369  1.200  0.429  0.514
0.109  0.771  0.700  0.420  0.356  2.400
 0.400  0.545  0.525  0.338  0.189  0.360  0.309  0.369  1.200  0.429  0.514
0.109  0.771  0.700  0.420  0.356  2.400
 0.400  0.545  0.525  0.338  0.189  0.360  0.309  0.369  0.686  0.429  0.514
0.109  0.771  0.700  0.420  0.356  2.400
 0.400  0.545  0.525  0.338  0.189  0.360  0.309  0.369  0.686  0.429  0.514
0.109  0.771  0.387  0.420  0.356  0.568
 0.400  0.545  0.525  0.338  0.189  0.360  0.309  0.369  0.686  0.429  0.514
0.109  0.900  0.387  0.420  0.356  0.568
 0.400  0.545  0.525  0.338  0.189  0.360  0.309  0.369  0.686  0.429  0.514
0.109  0.900  0.387  0.420  0.356  0.568
 0.400  0.545  0.525  0.338  0.189  0.360  0.309  0.369  0.686  0.429  0.514
0.109  0.369  0.387  0.284  0.356  0.568
 0.400  0.545  0.525  0.338  0.189  0.360  0.309  0.369  0.686  0.429  0.514
0.343  0.369  0.387  0.284  0.356  0.568
 0.400  0.545  0.525  0.338  0.189  0.360  0.309  0.369  0.686  0.429  0.514
0.343  0.369  0.387  0.284  0.356  0.568
 0.400  0.545  0.525  0.338  0.189  0.360  0.309  0.369  0.360  0.429  0.514
0.343  0.369  0.387  0.284  0.356  0.568
```

Sample **RAIN.DAT** input file for CASC2D - Continued

```
 0.400  0.545  0.525  0.338  0.189  0.360  0.309  0.369  0.360  0.429  0.514
0.343  0.369  0.387  0.284  0.356  0.568
 0.400  0.545  0.525  0.338  0.189  0.360  0.309  0.369  0.360  0.429  0.314
0.343  0.369  0.387  0.284  0.356  0.568
 0.400  0.545  0.525  0.400  0.189  0.360  0.309  0.369  0.360  0.333  0.314
0.343  0.369  0.387  0.284  0.356  0.568
 0.300  0.545  0.300  0.400  0.189  0.360  0.309  0.369  0.360  0.333  0.314
0.343  0.369  0.387  0.284  0.356  0.568
 0.300  0.545  0.300  0.400  0.189  0.360  0.309  0.369  0.360  0.333  0.314
0.343  0.369  0.387  0.284  0.356  0.568
 0.300  0.545  0.300  0.400  0.075  0.360  0.309  0.369  0.360  0.333  0.314
0.343  0.369  0.387  0.284  0.356  0.568
 0.300  0.545  0.300  0.400  0.075  0.360  0.309  0.369  0.360  0.333  0.314
0.343  0.369  0.387  0.284  0.356  0.568
 0.300  0.545  0.300  0.400  0.075  0.360  0.309  0.369  0.360  0.333  0.314
0.343  0.369  0.387  0.284  0.356  0.568
 0.300  0.545  0.300  0.400  0.075  0.360  0.309  0.369  0.360  0.333  0.314
0.343  0.369  0.387  0.284  0.356  0.568
 0.300  0.545  0.300  0.400  0.075  0.360  0.309  0.369  0.320  0.333  0.314
0.343  0.353  0.387  0.284  0.356  0.568
 0.300  0.545  0.300  0.400  0.075  0.360  0.309  0.369  0.320  0.333  0.314
0.343  0.353  0.387  0.284  0.356  0.568
 0.738  0.545  0.300  0.400  0.075  0.360  0.309  0.369  0.320  0.333  0.314
0.343  0.353  0.387  0.284  0.356  0.568
 0.738  0.545  0.300  0.400  0.075  0.360  0.309  0.369  0.320  0.333  0.314
0.343  0.353  0.387  0.284  0.356  0.400
 0.738  0.545  0.300  0.400  0.075  0.360  0.309  0.369  0.320  0.333  0.314
0.343  0.353  0.387  0.284  0.356  0.400
 0.738  0.545  0.300  0.400  0.075  0.360  0.309  0.369  0.320  0.333  0.314
0.343  0.353  0.387  0.284  1.560  0.400
 0.738  0.545  0.300  0.400  0.075  0.360  0.309  0.369  0.320  0.333  0.314
0.343  0.353  0.387  0.382  1.560  0.400
 0.738  0.545  0.300  0.400  0.075  0.360  0.309  0.369  0.320  0.333  0.314
0.343  0.353  0.387  0.382  1.560  0.400
 0.738  0.545  0.300  0.400  0.075  0.640  0.309  0.369  0.320  0.333  0.314
0.343  0.353  0.387  0.382  1.560  0.400
 0.738  0.545  0.300  0.400  0.075  0.640  0.309  0.369  0.320  0.333  0.314
1.029  0.353  0.387  0.382  1.560  0.400
 0.738  0.545  0.300  0.400  0.075  0.640  0.309  0.369  0.320  0.333  0.314
1.029  0.353  0.387  0.382  0.420  0.400
 0.738  0.545  0.300  1.200  0.075  0.640  0.309  0.369  0.320  0.764  0.314
1.029  0.353  0.387  0.382  0.420  0.400
 0.738  0.545  0.300  1.200  0.600  0.640  0.309  0.369  0.320  0.764  0.314
1.029  0.353  0.387  0.382  0.420  0.400
 0.738  0.545  0.300  1.200  0.600  0.640  0.309  0.369  0.320  0.764  0.760
1.029  0.353  0.387  0.382  0.420  0.400
 0.738  0.545  0.300  1.200  0.600  0.640  0.309  0.369  0.320  0.764  0.760
1.029  0.353  0.387  0.382  0.420  0.400
 0.655  0.545  0.300  1.200  0.600  0.640  0.309  0.369  0.333  0.764  0.760
1.029  0.353  0.660  0.382  0.420  0.400
 0.655  0.545  0.300  1.200  0.600  0.640  1.350  0.369  0.333  0.764  0.760
0.600  0.353  0.660  0.382  0.420  0.400
 0.655  0.545  0.300  1.200  0.600  0.640  1.350  1.133  0.333  0.764  0.760
0.600  0.600  0.660  0.500  0.420  0.400
 0.655  0.545  1.200  0.700  0.600  0.640  1.350  1.133  0.333  0.764  0.760
0.600  0.600  0.660  0.500  0.420  0.400
 0.655  0.545  1.200  0.700  0.600  0.640  1.350  1.133  0.333  0.764  0.760
0.600  0.600  0.660  0.500  0.420  0.400
 0.655  0.545  1.200  0.700  0.600  0.640  0.386  1.133  0.333  0.764  0.760
0.600  1.500  0.660  0.500  0.900  0.400
 0.655  0.545  1.200  0.700  0.600  0.640  0.386  1.133  0.333  0.764  0.760
0.600  1.500  0.660  0.500  0.900  0.533
 0.655  0.240  1.200  0.700  0.600  0.640  0.386  1.133  0.333  0.667  0.760
0.600  0.500  0.660  0.500  0.900  0.533
 0.655  0.240  1.200  0.700  0.600  2.100  0.386  1.133  0.333  0.667  0.760
0.600  0.500  0.660  1.200  0.900  0.533
```

Sample **RAIN.DAT** input file for CASC2D - Continued

```
   0.655    0.240    0.720    1.500    1.200    2.100    0.386    1.133    4.800    0.667    0.760
0.600    0.500    0.660    1.200    0.094    0.533
   0.655    0.240    0.720    1.500    1.200    2.100    0.386    1.133    0.700    0.667    0.760
1.200    0.500    0.600    1.200    0.094    0.533
   3.000    0.240    0.720    1.500    1.200    2.100    0.386    0.600    0.700    0.667    0.760
1.200    0.500    0.600    0.300    0.094    0.533
   0.221    0.240    0.720    1.500    0.282    0.300    0.386    0.600    0.700    0.667    0.760
1.200    0.500    1.200    0.300    0.094    0.533
   0.221    0.240    0.720    0.150    0.282    0.300    0.386    0.600    0.700    0.667    0.800
0.273    1.400    1.200    0.300    0.094    0.533
   0.221    0.240    0.720    0.150    0.282    0.300    0.386    0.600    0.700    0.667    0.800
0.273    1.400    1.200    0.300    0.094    0.533
   0.221    0.240    0.720    0.150    0.282    0.300    0.386    0.600    0.700    0.667    0.800
0.273    1.400    1.200    0.300    0.094    0.120
   0.221    0.240    0.720    0.150    0.282    0.300    0.386    0.600    0.514    0.257    0.171
0.273    0.191    0.106    0.300    0.094    0.120
   0.221    0.240    0.720    0.150    0.282    0.300    0.386    0.600    0.514    0.257    0.171
0.273    0.191    0.106    1.050    0.094    0.120
   0.221    0.240    0.720    0.150    0.282    0.300    0.386    3.000    0.514    0.257    0.171
0.273    0.191    0.106    1.050    0.094    0.120
   0.221    0.240    3.000    0.150    0.282    0.300    1.000    3.000    0.514    0.257    0.171
0.273    0.191    0.106    1.050    0.094    0.120
   0.221    0.240    0.212    0.150    0.282    0.024    1.000    0.185    0.514    0.257    0.171
0.273    0.191    0.106    1.050    0.094    0.086
   0.221    0.240    0.212    0.150    0.282    0.024    1.000    0.185    0.514    0.257    0.171
0.273    0.191    0.106    0.160    0.094    0.086
```

Sample **RAIN.DAT** input file for CASC2D - Continued

```
 28.99   4.00   0.037
 32.71   4.20   0.037
 23.45   4.34   0.037
 18.35   4.34   0.037
 15.24   4.50   0.037
 17.70   4.70   0.037
 37.97   4.97   0.037
 28.24   5.32   0.037
 23.63   6.05   0.037
 12.88   3.87   0.037
 22.42   3.98   0.037
 14.48   4.11   0.037
 15.70   3.40   0.037
 16.32   3.55   0.037
 13.65   3.83   0.037
 8.58    4.30   0.037
 7.42    4.50   0.037
 6.00    3.00   0.037
 7.00    3.50   0.037

13 13 13 13 13 13 12 12 12 11 11 11 11 11 11 -1     Channel 1
69 68 67 66 65 64 64 63 62 62 61 60 59 58 57 -1

11 11 12 12 12 12 12 13 14 14 15 15 16 16 16 -1     Channel 2
57 56 56 55 54 53 52 52 52 51 51 50 50 49 48 -1

16 16 16 16 16 15 15 15 14 14 14 14 14 -1  0  0     Channel 3
48 47 46 45 44 44 43 42 42 41 40 39 38 -1  0  0

14 15 15 15 16 16 17 18 19 19 20 20 21 -1  0  0     Channel 4
38 38 37 36 36 35 35 35 35 34 34 33 33 -1  0  0

21 21 22 22 23 23 24 24 25 25 25 25 -1  0  0  0     Channel 5
33 32 32 31 31 30 30 29 29 28 27 26 -1  0  0  0

25 25 25 25 25 25 25 25 26 26 -1  0  0  0  0  0     Channel 6
26 25 24 23 22 21 20 19 19 18 -1  0  0  0  0  0

26 26 27 27 27 28 29 30 30 31 31 32 -1  0  0  0     Channel 7
18 17 17 16 15 15 15 15 14 14 13 13 -1  0  0  0

32 32 33 34 34 35 36 36 37 37 38 39 39 40 41 -1     Channel 8
13 12 12 12 11 11 11 10 10  9  9  9  8  8  8 -1

41 41 42 43 43 44 44 44 44  0  0  0  0  0  0  0     Channel 9
 8  7  7  7  6  6  5  4  3  0  0  0  0  0  0  0

 8  8  9  9  9  9  9  9  9  9 10 -1  0  0  0  0    Channel 10
49 48 48 47 46 45 44 43 42 41 41 -1  0  0  0  0
```

Sample CHN.DAT input file for CASC2D

```
10 11 11 12 12 13 13 14 -1  0  0  0  0  0  0  0     Channel 11
41 41 40 40 39 39 38 38 -1  0  0  0  0  0  0  0

17 17 17 17 18 18 18 18 18 17 17 16 -1  0  0  0     Channel 12
56 55 54 53 53 52 51 50 49 49 48 48 -1  0  0  0

23 23 24 24 25 25 25 25 26 26 27 27 27 27 -1  0     Channel 13
57 56 56 55 55 54 53 52 52 51 51 50 49 48 -1  0

27 28 28 28 27 27 26 26 25 25 24 24 23 23 -1  0     Channel 14
48 48 47 46 46 45 45 44 44 43 43 42 42 41 -1  0

23 23 23 22 22 22 22 22 21 21 21 -1  0  0  0  0     Channel 15
41 40 39 39 38 37 36 35 35 34 33 -1  0  0  0  0

33 33 32 32 32 31 31 30 30 30 29 -1  0  0  0  0     Channel 16
37 36 36 35 34 34 33 33 32 31 31 -1  0  0  0  0

29 28 28 27 27 26 26 26 26 25 -1  0  0  0  0  0     Channel 17
31 31 30 30 29 29 28 27 26 26 -1  0  0  0  0  0

38 37 37 36 35 35 34 34 34 33 33 32 31 31 30 -1     Channel 18
29 29 28 28 28 27 27 26 25 25 24 24 24 23 23 -1

30 30 29 29 28 28 27 27 27 26 -1  0  0  0  0  0     Channel 19
23 22 22 21 21 20 20 19 18 18 -1  0  0  0  0  0
```

Sample **CHN.DAT** input file for CASC2D - Continued

APPENDIX D - Computer Program Listing for CASC2D

```
C     WITH INFILTRATION
C     WITH CHANNEL ROUTING #5
C     WITH PLOTING ROUTINE
C     PROGRAM DIFMACK
C     ==============
$NOLIST
      INCLUDE 'fGRAPH.FI'
      INCLUDE 'FGRAPH.FD'
$LIST
C
      INTEGER*1  ISHP(47,75),IMAN(47,75),ISOIL(47,75)
      COMMON /BLOK1/ E(47,75),H(47,75),RINT(47,75),VINF(47,75)
      COMMON /BLOK2/ DQOV(47,75),DQCH(47,75),HCH(47,75),
     +               XRG(20),YRG(20),RRG(20),PMAN(10),PINF(10,3),
     +               ICHN(29,16,2),CHP(29,3),IQ(20,2),Q(20)
      RECORD /videoconfig/ screen
      COMMON screen
C
      CALL FONTS()
      CALL GETTIM(IHR,IMIN,ISEC,I100)
C     ------------------------------------------------------------
C     OPENING FILES
C     ------------------------------------------------------------
      OPEN(UNIT=21,FILE='SHAP.DAT')
      OPEN(UNIT=22,FILE='ELAVG.DAT')
      OPEN(UNIT=23,FILE='RAIN.DAT')
      OPEN(UNIT=24,FILE='SOIL.DAT')
      OPEN(UNIT=25,FILE='DATA1')
      OPEN(UNIT=26,FILE='CHN.DAT')
      OPEN(UNIT=27,FILE='OUT.PRN')
      OPEN(UNIT=28,FILE='IMAN.DAT')
      OPEN(UNIT=29,FILE='DISCHARGE.OUT')
      OPEN(UNIT=36,FILE='DEPTH.OUT')
C     ------------------------------------------------------------
      WRITE(27,'('' Started at '',I2,'':'',I2,'':'',I2)')IHR,IMIN,ISEC
      WRITE(27,222)
C
      READ(25,*) M,N,W,NMAN,SDEP
      READ(25,*) DT,NITER,NITRN,NPRN,NPLT
      READ(25,*) JOUT,KOUT,SOUT,qmax,WCHOUT,DCHOUT,RMANOUT
      READ(25,*) INDEXINF,NSOIL
      READ(25,*) NCHN,MAXCHN
      READ(25,*) IDEPPLT
      READ(25,*) IRAIN
C
      IF(IRAIN.EQ.0) READ(25,*) CRAIN
      IF(IRAIN.EQ.1) READ(25,*) NRG,NREAD
      IF(IRAIN.EQ.1) READ(25,*) (XRG(L),YRG(L),L=1,NRG)
C
      READ(25,*) (PMAN(J),J=1,NMAN)
      IF(INDEXINF.EQ.1) READ(25,*) ((PINF(J,K),K=1,3),J=1,NSOIL)
      READ(25,*) INDEXDIS,NDIS
      IF(INDEXDIS.EQ.1) READ(25,*) ((IQ(J,K),K=1,2),J=1,NDIS)
C
      IF(NCHN.NE.0) READ(26,*) ((CHP(L,K),K=1,3),L=1,NCHN)
      IF(NCHN.NE.0) READ(26,128) (((ICHN(L,J,K),J=1,MAXCHN),
     +                          K=1,2),L=1,NCHN)
 128  FORMAT(/16I3/16I3)
      WRITE(29,229) ((IQ(J,K),K=1,2),J=1,NDIS)
C     ---------------------------------------------------------
C     READING SHAP MATIX AND READING ELEVATIONS AND INITIALIZATIONS
C     ---------------------------------------------------------
      DO 150 J=1,M
      DO 150 K=1,N
      READ(21,*) ISHP(J,K)
      READ(22,*) E(J,K)
```

Computer Listing for CASC2D MODEL

```
      IF(NSOIL.EQ.1) THEN
      ISOIL(J,K)=1
      ELSE
      READ(24,*) ISOIL(J,K)
      ENDIF
      IF(NMAN.EQ.1) THEN
      IMAN(J,K)=1
      ELSE
      READ(28,*) IMAN(J,K)
      ENDIF
C
      H(J,K)=0.
      HCH(J,K)=0.
      DQOV(J,K)=0.
      DQCH(J,K)=0.
      VINF(J,K)=0.
c           RTOT(j,k)=0.
  150 CONTINUE
C     ----------------------------------------
      DO 160 IC=1,NCHN,1
      DO 175 L=1,MAXCHN,1
      J=ICHN(IC,L,1)
      K=ICHN(IC,L,2)
      IF(J.LE.0) GO TO 160
      ISHP(J,K)=2
  175 CONTINUE
  160 CONTINUE
C     ----------------------------------------------------
      VIN=0.
      VOUT=0.
      VSUR=0.
      VINFTOT=0.
      RINDEX=1.
C     ----------------------------------------
C     TIME LOOP
C     ----------------------------------------
      DO 10 I=1,NITER
      IF(IDEPPLT.EQ.0)  WRITE(*,*)I
      ICALL=0
      IF(I.GT.NITRN)  RINDEX=0.
      IF(I.LE.NITRN.AND.IRAIN.EQ.1)  THEN
      IF(((I-1)/NREAD)*NREAD.EQ.(I-1)) THEN
      ICALL=1
      READ(23,124) (RRG(L),L=1,NRG)
c------->
c      change the format from 17 to the new number of raingages
c-------->
  124 FORMAT(17F9.3)
      ENDIF
      ENDIF
C        ----------------------------------------------------
      DO 1 J=1,M
      DO 1 K=1,N
      IF(ISHP(J,K).EQ.0) GO TO 1
      IF(IRAIN.EQ.0) THEN
      RINT(J,K)=CRAIN
      ELSE
      IF(ICALL.EQ.1) CALL RAIN(J,K,NRG,XRG,YRG,RRG,RINT)
      ENDIF
      IF(I.GT.NITRN) RINT(J,K)=0.
c             RTOT(J,K)=RTOT(J,K)+RINT(J,K)*DT
C
      HOV=DQOV(J,K)*DT/(W*W)
      HOV=HOV+H(J,K)+RINDEX*RINT(J,K)*DT
      IF(HOV.LT.0) GO TO 170
      IF(INDEXINF.EQ.1)CALL INFILT(J,K,DT,ISOIL,VINF,PINF,HOV)
```

Computer Listing for CASC2D MODEL - Continued

```
      H(J,K)=HOV
      DQOV(J,K)=0.
      VIN=VIN+RINDEX*RINT(J,K)*DT*W*W
      IF(I.EQ.NITER) VINFTOT=VINFTOT+VINF(J,K)*W*W
      IF(I.EQ.NITER.AND.ISHP(J,K).EQ.1) VSUR=VSUR+H(J,K)*W*W
    1 CONTINUE
C      ----------------------------------------------------
      DO 2 IC=1,NCHN,1
      DO 3 L=1,MAXCHN,1
      J=ICHN(IC,L,1)
      K=ICHN(IC,L,2)
      JJ=ICHN(IC,L+1,1)
      IF(J.LE.0) GO TO 2
      IF(JJ.LT.0) GO TO 2
      WCH=CHP(IC,1)
      DCH=CHP(IC,2)
      DHCH=DQCH(J,K)*DT/(W*WCH)
      HCH(J,K)=HCH(J,K)+DHCH
      IF(H(J,K).GT.SDEP) THEN
      HCH(J,K)=HCH(J,K)+(H(J,K)-SDEP)*W/WCH
      H(J,K)=SDEP
      ENDIF
      HTOP=DCH+H(J,K)
      IF(HCH(J,K).GT.HTOP) THEN
      DH=(HCH(J,K)-HTOP)*WCH/W
      H(J,K)=H(J,K)+DH
      HCH(J,K)=HTOP+DH
      ENDIF
      IF(HCH(J,K).LT.0) GO TO 170
      DQCH(J,K)=0.
      IF(I.EQ.NITER) VSUR=VSUR+HCH(J,K)*W*WCH+H(J,K)*W*W
    3 CONTINUE
    2 CONTINUE
C     ----------------------------------------------------------
   11 DO 20 J=1,M
      DO 30 K=1,N
      IF(ISHP(J,K).EQ.0) GO TO 30
      DO 40 L=-1,0,1
      JJ=J+L+1
      KK=K-L
C               ----------------------------------------------
      IF(JJ.GT.M.OR.KK.GT.N.OR.ISHP(JJ,KK).EQ.0) GO TO 40
      CALL OVRL(W,IMAN,PMAN,SDEP,J,K,JJ,KK,E,H,DQOV)
   40 CONTINUE
   30 CONTINUE
   20 CONTINUE
C     ---------------------------------------------
      DO 50 IC=1,NCHN,1
      WCH=CHP(IC,1)
      DCH=CHP(IC,2)
      RMANCH=CHP(IC,3)
      DO 60 L=1,MAXCHN-1,1
      J=ICHN(IC,L,1)
      K=ICHN(IC,L,2)
      JJ=ICHN(IC,L+1,1)
      KK=ICHN(IC,L+1,2)
      JJJ=ICHN(IC,L+2,1)
      IF(JJ.LE.0) GO TO 50
      CALL CHNCHN(NCHN,W,WCH,DCH,RMANCH,
     +               J,K,JJ,KK,JJJ,E,HCH,ICHN,CHP,DQCH,NDIS,IQ,Q)
   60 CONTINUE
   50 CONTINUE
C     ---------------------------------------------
C        OUTFLOW DISCHARGE
C     ---------------------------------------------
      HOUT=H(JOUT,KOUT)
```

Computer Listing for **CASC2D MODEL** - Continued

```
      ALFA=SQRT(SOUT)/PMAN(IMAN(JOUT,KOUT))
      QOUTOV=0.
      IF(HOUT.GT.SDEP) QOUTOV=W*ALFA*((HOUT-SDEP)**1.667)
      H(JOUT,KOUT)=HOUT-QOUTOV*DT/(W*W)
C
      HOUT=HCH(JOUT,KOUT)
      WPOUT=WCHOUT+2.*HOUT
      IF(HOUT.GT.DCHOUT) WPOUT=WCHOUT+2.*DCHOUT
      AREAOUT=WCHOUT*HOUT
      ALFA=SQRT(SOUT)/RMANOUT
      QOUTCH=ALFA*(AREAOUT**1.6667)/(WPOUT**0.6667)
      HCH(JOUT,KOUT)=HOUT-QOUTCH*DT/(W*WCHOUT)
      QOUT=QOUTOV+QOUTCH
      VOUT=VOUT+QOUT*DT
C     ---------------------------------------------------
      if(i.eq.1) then
      qpeak=0.
      tpeak=0.
      endif
      if(qout.gt.qpeak) then
      qpeak=qout
      tpeak=real(i)*dt/60.
      endif
c
      if(i.eq.1) qold = 0.0
      IF((IDEPPLT.EQ.1).AND.(((I-1)/NPLT)*NPLT).EQ.I-1)
     +      CALL DEPPLT(I,NPLT,ISHP,RINT,NITRN,IRAIN,ICALL,VINF,
     +      INDEXINF,H,HCH,niter,dt,qout,qold,qmax,m,n)
      IF(((I-1)/NPLT)*NPLT.EQ.I-1) qold = qout
C     ----------------------------------------------------
C----->>>    UNIT CHANGE FROM m3/s TO cfs
      IF((I/NPRN)*NPRN.EQ.I) WRITE(27,111) I*DT/60.,QOUT*(3.28)**3
      IF((I/NPRN)*NPRN.EQ.I) WRITE(29,112) I*DT/60.,
     +      (Q(ILL)*(3.28)**3,ILL=1,NDIS)
   10 CONTINUE
C
      WRITE(36,898)
      DO 899 J=1,M
      DO 899 K=1,N
      IF(ISHP(J,K).EQ.0) GO TO 899
      WRITE(36,891) J,K,1000.*H(J,K),1000.*VINF(J,K)
  899 CONTINUE
C     ----------------------------------------------------------
C----->>>    UNIT CHANGE FROM m3 TO ft3
      WRITE(27,113) qpeak*(3.28**3),tpeak,VIN*(3.28**3),
     +              VOUT*(3.28**3),100.*VOUT/VIN,VSUR*(3.28**3),
     +              100.*VSUR/VIN,VINFTOT*(3.28**3),100.*VINFTOT/VIN
     +              ,100.*(VOUT+VSUR+VINFTOT)/VIN
c
C     ----------------------------------------------------------
      GO TO 172
  170 WRITE(27,171) J,K,I*DT,HOV
  172 CONTINUE
      CALL GETTIM(IHR,IMIN,ISEC,I100)
      WRITE(27,'('' Stopped at '',I2,'':'',I2,'':'',I2)')IHR,IMIN,ISEC
C     -------------------------------------------------------------
  222 FORMAT(//' TIME(MIN)  DISCHARGE(CFS)'/)
  229 FORMAT('DISCHARGE AT: ',20(2I3,'    '))
  111 FORMAT(2X,F7.2,F14.3)
  112 FORMAT(2X,F7.2,20F10.3)
  113 FORMAT(//' PEAK DISCHARGE in CFS=',F15.3/' TIME TO PEAK in MIN=',
     +   F15.1/' VOLUME IN in FT3=',F20.1/' VOLUME OUT in FT3=',2F25.3
     +  /' SURFACE VOLUME in FT3=',2F25.3/' VOLUME INFILTRATED IN FT3='
     +  ,2F25.3/'PERCENT MASS BALANCE=',F25.3/)
  171 FORMAT(/'PROGRAM STOPPED FOR NEGATIVE DEPTH',2I4,2F15.6)
 1054 FORMAT(I10)
```

Computer Listing for CASC2D MODEL - Continued

```
  550 FORMAT(I4)
  898 FORMAT(' ROW  COLUMN  DEPTH(MM)  INILTRATION(MM)')
  891 FORMAT(2I6,2F10.0)
C     ------------------------------------------------------------
      IF(IDEPPLT.EQ.1)  read(*,*)
      idummy=setvideomode( $DEFAULTMODE)
      STOP
      END
C
C     =====================================
      SUBROUTINE RAIN(J,K,NRG,XRG,YRG,RRG,RINT)
C     =====================================
         DIMENSION XRG(NRG),YRG(NRG),RINT(47,75),RRG(NRG)
C
      RINT(J,K)=0.
      TOTDIST=0.
      TOTRAIN=0.
C
      DO 1 L=1,NRG
      REALJ=J
      REALK=K
      DIST=SQRT((REALJ-YRG(L))**2+(REALK-XRG(L))**2)
      IF(DIST.LT.1E-5) THEN
      RINT(J,K)=RRG(L)
      GO TO 2
      ENDIF
      TOTDIST=TOTDIST+1./(DIST**2)
      TOTRAIN=TOTRAIN+RRG(L)/(DIST**2)
    1 CONTINUE
      RINT(J,K)=TOTRAIN/TOTDIST
C----->>>     UNIT CHANGE FROM in/hr TO m/s
    2 RINT(J,K)=RINT(J,K)*0.0254/3600.
      RETURN
      END
C
C     ========================================
      SUBROUTINE INFILT(J,K,DT,ISOIL,VINF,PINF,HOV)
C     ========================================
      INTEGER*1  ISOIL(47,75)
      DIMENSION  VINF(47,75),PINF(10,3)
C
      IINF=ISOIL(J,K)
      HYDCON=PINF(IINF,1)
      CS=PINF(IINF,2)
      SMD=PINF(IINF,3)
C
      P1=HYDCON*DT-2.*VINF(J,K)
      P2=HYDCON*(VINF(J,K)+CS*SMD)
      RINF=(P1+SQRT(P1**2+8.*P2*DT))/(2.*DT)
      IF((HOV/DT).LE.RINF) THEN
      RINF=HOV/DT
      HOV=0
      ELSE
      HOV=HOV-RINF*DT
      ENDIF
      VINF(J,K)=VINF(J,K)+RINF*DT
      RETURN
      END
C
C     ================================================
      SUBROUTINE OVRL(W,INAN,PMAN,SDEP,J,K,JJ,KK,E,H,DQOV)
C     ================================================
      DIMENSION  E(47,75),H(47,75),DQOV(47,75),PMAN(10)
      INTEGER*1  INAN(47,75)
      DATA       A/1./
C
```

Computer Listing for CASC2D MODEL - Continued

```
      SO=(E(J,K)-E(JJ,KK))/W
      DHDX=(H(JJ,KK)-[illegible]K))/W
      SF=SO-DHDX+1E-[illegible]
      IF(ABS(SF).LT.[illegible] SF=1E-20
      HH=H(J,K)
      RMAN=PMAN(IMAN(J,K))
      IF(SF.LT.0) HH=H(JJ,KK)
      IF(SF.LT.0) RMAN=PMAN(IMAN(JJ,KK))
      IF(HH.LT.SDEP) RETURN
      ALFA=(ABS(SF)**0.5)/RMAN
      DQQ=SIGN(A,SF)*W*ALFA*((HH-SDEP)**1.667)
      DQOV(J,K)=DQOV(J,K)-DQQ
      DQOV(JJ,KK)=DQOV(JJ,KK)+DQQ
      RETURN
      END
C
C     ============================================================
      SUBROUTINE CHNCHN(NCHN,W,WCH,DCH,RMANCH,
     +           J,K,JJ,KK,JJJ,E,HCH,[illegible]P,DQCH,NDIS,IQ,Q)
C    =============================================================
      DIMENSION E(47,75),HCH(47,75),[illegible],CHP(29,3),
     +          DQCH(47,75),IQ(20,2),Q([illegible])
      DATA      A/1./
C
      SO=(E(J,K)-DCH-E(JJ,KK)+DCH)/W
      IF(JJJ.LT.0) THEN
      DO 5 IIC=1,NCHN,1
      IF(JJ.EQ.ICHN(IIC,1,1).AND.KK.EQ.ICHN(IIC,1,2)) THEN
      SO=(E(J,K)-DCH-E(JJ,KK)+CHP(IIC,2))/W
      IJUN=IIC
      GO TO 7
      ENDIF
    5 CONTINUE
      ENDIF
C
    7 DHDX=(HCH(JJ,KK)-HCH(J,K))/W
      SF=SO-DHDX+1E-30
      IF(ABS(SF).LT.1E-20) SF=1E-20
      HH=HCH(J,K)
      IF(SF.LT.0)  THEN
      WCH=CHP(IJUN,1)
      DCH=CHP(IJUN,2)
      RMANCH=CHP(IJUN,3)
      HH=HCH(JJ,KK)
      ENDIF
      WP=WCH+2.*HH
      IF(HH.GT.DCH) WP=WCH+2.*DCH
      AREA=WCH*HH
      DQ=SIGN(A,SF)*(SQRT(ABS(SF))/RMANCH)*(AREA**1.6667)/(WP**0.6667)
      DQCH(J,K)=DQCH(J,K)-DQ
      DQCH(JJ,KK)=DQCH(JJ,KK)+DQ
C
      DO 367 ILL=1,NDIS
      IF(SF.GE.0) THEN
      IF(J.EQ.IQ(ILL,1).AND.K.EQ.IQ(ILL,2)) Q(ILL)=DQ
      ELSE
      IF(JJ.EQ.IQ(ILL,1).AND.KK.EQ.IQ(ILL,2)) Q(ILL)=-1.*DQ
      ENDIF
  367 CONTINUE
C
      RETURN
      END
C     ===========================
      LOGICAL FUNCTION fourcolors()
C     ===========================
$NOLIST
```

Computer Listing for CASC2D MODEL - Continued

```
      INCLUDE 'FGRAPH.FD'
$LIST
      INTEGER*2 dummy
      RECORD /videoconfig/ screen
      COMMON screen
C
      CALL getvideoconfig( screen )
      if ((screen.mode.ne.3).and.(screen.mode.ne.7)) then
      fourcolors = .true.
      return
      endif
      SELECT CASE( screen.adapter )
      CASE( $EGA, $OEGA)
      dummy=setvideomode( $ERESCOLOR)
      CASE( $VGA )
      dummy=setvideomode( $VRES16COLOR)
      CASE DEFAULT
      dummy=0
      END SELECT
      CALL getvideoconfig( screen )
      fourcolors=.TRUE.
      IF(dummy.EQ.0) fourcolors=.FALSE.
      END
C
C     ==========================================================
      SUBROUTINE DEPPLT(i,nplt,ishp,rint,nitrn,irain,icall,vinf,
     +                  indexinf,h,hch,niter,dt,qout,qold,qmax,m,n)
C     ==========================================================
$NOLIST
      INCLUDE 'FGRAPH.FD'
$LIST
C
      CHARACTER*80  buffer
      INTEGER*1  ishp(47,75),idepcol(10),iinfcol(10),irancol(10)
      INTEGER*2 dummy,icolor
      DOUBLE PRECISION xx,yy
      LOGICAL fourcolors
      EXTERNAL fourcolors
      RECORD /wxycoord/ wxy
      RECORD /videoconfig/ screen
      COMMON screen
      DIMENSION  rint(47,75),vinf(47,75),h(47,75),hch(47,75)
      DIMENSION  rdep(10),rinfl(10),rrain(10),obser(1500,2)
      DATA       ndiv/4/
C
      OPEN(UNIT=31,FILE='coldyn.dat')
      OPEN(UNIT=32,FILE='observ.dat')
C     ------------------------------------------------------------------
      IF(i.EQ.1) THEN
      IF(.not. fourcolors()) THEN
      WRITE(*,*) 'THIS PROGRAM REQUIRES EGA OR VGA CARDS.'
      RETURN
      ENDIF
      READ(31,101) (idepcol(ic),rdep(ic),ic=1,10)
      READ(31,101) (iinfcol(ic),rinfl(ic),ic=1,10)
      READ(31,101) (irancol(ic),rrain(ic),ic=1,10)
  101 format (i3,f15.0)
C     ---------------------------------------------
      CALL clearscreen( $GCLEARSCREEN)
      nx=screen.numxpixels
      ny=screen.numypixels
      dummy=setcolor(15)
      dummy=setwindow(.FALSE.,0.,0.,160.*2,115.*2)
      dummy=rectangle_w( $GBORDER,0.*2,4.*2,80.*2,75.*2)
      dummy=rectangle_w( $GBORDER,80.*2,4.*2,160.*2,75.*2)
      dummy=rectangle_w( $GBORDER,0.*2,75.*2,38.*2,115.*2)
```

Computer Listing for **CASC2D MODEL** - Continued

```
      dummy=setcolor(15)
      dummy=rectangle_w( $GBORDER,38.*2,75.*2,160.*2,115.*2)
      dummy=setcolor(15)
      dummy=rectangle_w( $GFILLINTERIOR,125.*2,75.*2,160.*2,85.*2)
c        -----------------------------------------------
      dummy=setcolor(14)
      call moveto_w(2*42.,2*111.,wxy)
      dummy=lineto_w(2.*156.,2.*111.)
      call moveto_w(2*42.,2*111.,wxy)
      dummy=lineto_w(2.*42.,2.*79.)
c
      dummy=setcolor(14)
      DO 81 kj=1,ndiv,1
      call setlinestyle(#ffff)
      call moveto_w(2.*41.5,2.*(111.-kj*(111.-79.)/ndiv),wxy)
      dummy=lineto_w(2.*42.5,2.*(111.-kj*(111.-79.)/ndiv))
      call moveto_w(2.*(42.+kj*(156.-42.)/ndiv),2.*111.5,wxy)
      dummy=lineto_w(2.*(42.+kj*(156.-42.)/ndiv),2.*110.5)
      call setlinestyle(#8000)
      call moveto_w(2*42.,2.*(111.-kj*(111.-79.)/ndiv),wxy)
      dummy=lineto_w(2.*156.,2.*(111.-kj*(111.-79.)/ndiv))
      81 CONTINUE
      call setlinestyle(#ffff)
c        ------------------------------------------------------
c          OBSERVED DATA DISPLAY
c        ------------------------------------------------------
      dummy=setcolor(13)
      READ(32,*) nobser
      DO 82 ic=1,nobser,1
      READ(32,*) (obser(ic,kl),kl=1,2)
      if(ic.eq.1) go to 82
      if(obser(ic,1).GT.niter*dt/60.) go to 83
      xx = (obser(ic,1) *60./dt)*(156.-42.)/niter
      yy= (obser(ic,2)*(111.-79.))/qmax
      call moveto_w(2*(42.+xx),2*(111.-yy),wxy)
      xx = (obser(ic-1,1) *60./dt)*(156.-42.)/niter
      yy= (obser(ic-1,2)*(111.-79.))/qmax
      dummy=lineto_w(2*(42.+xx),2*(111.-yy))
   82 CONTINUE
  103 format(2f6.0)
c        ------------------------------------------------------
   83 dummy=setfont('t''modern''h8w6b')
      dummy=setcolor(14)
      call moveto_w(2*41.5,2*112.,wxy)
      write(buffer,201) 0
      call outgtext(buffer)
      call moveto_w(2*40.,2*110.3,wxy)
      write(buffer,201) 0
  201 format(i1)
c
      call outgtext(buffer)
      call moveto_w(2*150.,2*112.5,wxy)
      write(buffer,203) int(niter*dt/60.)
      call outgtext(buffer)
      call moveto_w(2*38.5,2*76.,wxy)
      write(buffer,200) int(qmax)
      call outgtext(buffer)
  200 format(i6)
  203 format(i5)
c        ----------------------------------------------
      dummy=setfont('t''modern''h16w16b')
      dummy=setcolor(14)
      call moveto_w(2*33.,2*0.,wxy)
      call outgtext("Goodwin Creek Watershed")
      call moveto_w(2*32.8,2*0.,wxy)
      call outgtext("Goodwin Creek Watershed")
```

```
      dummy=setfont('t''modern''h13w13b')
      dummy=setcolor(10)
      call moveto_w(2*11.,2*5.,wxy)
      call outgtext("Rainfall Rate (in/h)")
      call moveto_w(2*10.8,2*5.,wxy)
      call outgtext("Rainfall Rate (in/h)")
      dummy=setcolor(10)
      call moveto_w(2*94.,2*5.,wxy)
      call outgtext("Surface Depth (m)")
      call moveto_w(2*93.7,2*5.,wxy)
      call outgtext("Surface Depth (m)")
      dummy=setfont('t''modern''h11w8b')
      dummy=setcolor(10)
      call moveto_w(2*2.3,2*76.,wxy)
      call outgtext("Infiltration Depth (m)")
c       ----------------------------------------------
      dummy=setfont('t''modern''h9w8b')
      dummy=setcolor(12)
      call moveto_w(2*90.,2*112.,wxy)
      call outgtext("Time (min)")
      call moveto_w(2*38.05,2*92.,wxy)
      call outgtext(" Q")
      dummy=setfont('t''modern''h7w6b')
      call moveto_w(2*38.1,2*95.,wxy)
      call outgtext("cfs")
c
      dummy=setcolor(0)
      dummy=rectangle_w( $GFILLINTERIOR,126.*2,76.*2,159.*2,84.*2)
      dummy=setcolor(11)
      dummy=setfont('t''modern''h12w8b')
      call moveto_w(2*127.,2*77.,wxy)
      call outgtext("Time = ")
      call moveto_w(2*127.,2*80.,wxy)
      call outgtext("Qout = ")
c     ------------------------------------
c     create color bars for depth and rainfall
c     ------------------------------------
      DO  20 II=1,10
      dummy=setfont('t''modern''h8w6b')
      dummy=setcolor(irancol(II))
      dummy=rectangle_w( $GFILLINTERIOR,2*4.,2*(41.-3.*II)
     +                      ,2*9.,2*(43.-3.*II))
      dummy=setcolor(idepcol(II))
      dummy=rectangle_w( $GFILLINTERIOR,2*84.,2*(41.-3.*II)
     +                      ,2*89.,2*(43.-3.*II))
      dummy=setcolor(iinfcol(II))
      dummy=rectangle_w( $GFILLINTERIOR,2.*2,2*(95.-1.5*II)
     +                      ,2.*4,2*(96.-1.5*II))
   20 CONTINUE
      dummy=setcolor(15)
c
      DO 22 II=1,9
      dummy=setfont('t''modern''h8w6b')
      call moveto_w(2*10.,2*(40.-3.*II),wxy)
      write(buffer,102) rrain(II)
      call outgtext(buffer)
c
      call moveto_w(2*90.,2*(40.-3.*II),wxy)
      write(buffer,105) rdep(II)
      call outgtext(buffer)
c
      dummy=setfont('t''modern''h6w4b')
      call moveto_w(2.*5,2.*(94.1-1.5*II),wxy)
      write(buffer,105) rinfl(II)
      call outgtext(buffer)
   22 CONTINUE
```

Computer Listing for CASC2D MODEL - Continued

```
  102 format(f5.2)
  105 format(1pe6.0)
      ENDIF
C     ----------------------------------------------------------      DO 10 j=1,m
      DO 10 k=1,n
      IF(ishp(j,k).EQ.0) GO TO 10
      IF(ishp(j,k).EQ.1) hh=h(j,k)
      IF(ishp(j,k).EQ.2) hh=hch(j,k)
      IF(hh.LT.rdep(1))                     icolor=idepcol(1)
      IF(hh.GE.rdep(1).AND.hh.LT.rdep(2)) icolor=idepcol(2)
      IF(hh.GE.rdep(2).AND.hh.LT.rdep(3)) icolor=idepcol(3)
      IF(hh.GE.rdep(3).AND.hh.LT.rdep(4)) icolor=idepcol(4)
      IF(hh.GE.rdep(4).AND.hh.LT.rdep(5)) icolor=idepcol(5)
      IF(hh.GE.rdep(5).AND.hh.LT.rdep(6)) icolor=idepcol(6)
      IF(hh.GE.rdep(6).AND.hh.LT.rdep(7)) icolor=idepcol(7)
      IF(hh.GE.rdep(7).AND.hh.LT.rdep(8)) icolor=idepcol(8)
      IF(hh.GE.rdep(8).AND.hh.LT.rdep(9)) icolor=idepcol(9)
      IF(hh.GT.rdep(9))                     icolor=idepcol(10)
      dummy=setcolor(icolor)
      dummy=rectangle_w( $GFILLINTERIOR,2.*(k+3+80),2.*(j+25)
     +                ,2.*(k+4+80),2.*(j+26))
      IF(indexinf.EQ.0) GO TO 11
      vv=vinf(j,k)
      IF(vv.LT.rinfl(1))                      icolor=iinfcol(1)
      IF(vv.GE.rinfl(1).AND.vv.LT.rinfl(2)) icolor=iinfcol(2)
      IF(vv.GE.rinfl(2).AND.vv.LT.rinfl(3)) icolor=iinfcol(3)
      IF(vv.GE.rinfl(3).AND.vv.LT.rinfl(4)) icolor=iinfcol(4)
      IF(vv.GE.rinfl(4).AND.vv.LT.rinfl(5)) icolor=iinfcol(5)
      IF(vv.GE.rinfl(5).AND.vv.LT.rinfl(6)) icolor=iinfcol(6)
      IF(vv.GE.rinfl(6).AND.vv.LT.rinfl(7)) icolor=iinfcol(7)
      IF(vv.GE.rinfl(7).AND.vv.LT.rinfl(8)) icolor=iinfcol(8)
      IF(vv.GE.rinfl(9).AND.vv.LT.rinfl(9)) icolor=iinfcol(9)
      IF(vv.GT.rinfl(9))                      icolor=iinfcol(10)
      dummy=setcolor(icolor)
      dummy=rectangle_w( $GFILLINTERIOR,k,
     +            j+2.*75+27,k+1,j+2.*75+28)
C
   11 IF(i.GT.nitrn+nplt+1) GO TO 10
      IF(irain.eq.0.AND.i.ne.1.AND.i.lt.nitrn) GO TO 10
      IF(irain.eq.1.AND.icall.eq.0.AND.i.lt.nitrn) GO TO 10
C-----------------------------------------------------------------------
C       change rain from m/s to in/hr
C-----------------------------------------------------------------------
      rr=rint(j,k)*(100)*3600/2.54
      IF(i.gt.nitrn+1) rr=0.
      IF(rr.LT.rrain(1))                      icolor=irancol(1)
      IF(rr.GE.rrain(1).AND.rr.LT.rrain(2)) icolor=irancol(2)
      IF(rr.GE.rrain(2).AND.rr.LT.rrain(3)) icolor=irancol(3)
      IF(rr.GE.rrain(3).AND.rr.LT.rrain(4)) icolor=irancol(4)
      IF(rr.GE.rrain(4).AND.rr.LT.rrain(5)) icolor=irancol(5)
      IF(rr.GE.rrain(5).AND.rr.LT.rrain(6)) icolor=irancol(6)
      IF(rr.GE.rrain(6).AND.rr.LT.rrain(7)) icolor=irancol(7)
      IF(rr.GE.rrain(7).AND.rr.LT.rrain(8)) icolor=irancol(8)
      IF(rr.GE.rrain(8).AND.rr.LT.rrain(9)) icolor=irancol(9)
      IF(rr.GT.rrain(9))                      icolor=irancol(10)
      dummy=setcolor(icolor)
      dummy=rectangle_w( $GFILLINTERIOR,2.*(k+3),2.*(j+25)
     +             ,2.*(k+4),2.*(j+26))
   10 CONTINUE
C     ----------------------------------------------------------
      dummy=setcolor(0)
      dummy=rectangle_w( $GFILLINTERIOR,138.*2,76.*2,159.*2,84.*2)
      dummy=setfont('t''modern''h12w8b')
      dummy=setcolor(11)
      call moveto_w(2.*148.,2.*77.,wxy)
      write(buffer,122) i*dt/60.
```

Computer Listing for CASC2D MODEL - Continued

```
      call outgtext(buffer)
      call moveto_w(2.*148.,2.*81.,wxy)
      write(buffer,122) qout*3.28**3
      call outgtext(buffer)
  122 format(f6.1)
      xx = 1.*(i-nplt) / (1.*niter)
      if((i-nplt).lt.0) xx=0.
      xx = xx * (156.-42.)
      xx = xx + 42.
      yy = qold*3.28**3 / qmax
      yy = yy * (111.-79.)
      yy = 111. - yy
      call moveto_w(2*xx,2*yy,wxy)
      xx = 1.*i / (1.*niter)
      xx = xx * (156.-42)
      xx = xx + 42.
      yy = qout*3.28**3 / qmax
      yy = yy * (111.-79.)
      yy = 111. - yy
      dummy=setcolor(12)
      dummy=lineto_w(2*xx,2*yy)
      RETURN
      END
C     ============================
C     SET UP FONTS FOR GRAPHICS MODE
C     ============================
      SUBROUTINE FONTS()
$NOLIST
      INCLUDE 'FGRAPH.FD'
$LIST
      INTEGER*2 IDUM2,I,J
      CHARACTER*64 FPATH
      IDUM2=REGISTERFONTS('*.FON')
      IF (IDUM2 .GE. 0) GO TO 1010
 1000 WRITE(*,'('' Enter path to font files (drive:\dir1\dir2...) ''
     +,\))')
      READ(*,'(A64)') FPATH
      DO 1005 I=1,64
 1005 IF((FPATH(I:I).NE.' ').AND.(J.EQ.I-1)) J=I
      IF (FPATH(J:J).NE.'\') THEN
      J=J+1
      FPATH(J:J)='\'
      ENDIF
      FPATH = FPATH(1:J) // '*.FON'
      IDUM2=REGISTERFONTS(FPATH)
      IF (IDUM2.LT.0) GO TO 1000
 1010 IDUM2=SETFONT('t''roman''h12w12b')
      RETURN
      END
```

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13. ABSTRACT *(Maximum 200 words)*

The purpose of monitoring the Demonstration Erosion Control (DEC) Project is to evaluate and document watershed response to the implemented DEC Project. Documentation of watershed responses to DEC Project features will allow the participating agencies a unique opportunity to determine the effectiveness of existing design guidance for erosion and flood control in small watersheds. The monitoring program includes 11 technical areas: stream gaging, data collection and data management, hydraulic performance of structures, channel response, hydrology, upland watersheds, reservoir sedimentation, environmental aspects, bank stability, design tools, and technology transfer.

This appendix presents the results of three hydrologic modeling techniques that have been compared to observed data to assess the accuracy of the computed hydrographs. The principal objective of this study was to evaluate a new two-dimensional spatially distributed hydrologic model versus observed watershed rainfall and streamflow data. An additional objective was to compare the results to traditional methods for estimating rainfall-runoff used in the Corps of Engineers HEC-1 Flood Hydrograph Package computer model. This study was performed with the primary goal of determining whether a two-dimensional approach to hydrologic modeling using spatially varied data would perform at least as well as traditional unit hydrograph methods for estimating rainfall-runoff over an ungaged watershed.

(Continued)

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The watershed area to which the models have been applied is Goodwin Creek located in north Mississippi near Batesville. Goodwin Creek, with an area of approximately 8.4 square miles, has been extensively monitored by the Agricultural Research Service located in Oxford, MS. This watershed along with the extensive measured rainfall and streamflow data offers a unique opportunity to compare watershed hydrology models for the purpose of assessing their performance.

The rainfall-runoff techniques evaluated were Snyder's and Soil Conservation Service's (SCS's) unit hydrograph methods in the HEC-1 computer model, and a two-dimensional diffusive wave overland flow routing method (CASC2D) developed at Colorado State University. For comparison purposes, the Green-Ampt infiltration scheme used in the CASC2D model was also used in the HEC-1 computer model. Also, the Muskingum-Cunge channel routing option in HEC-1 was used in order to be comparable to the one-dimensional diffusive wave channel routing method of the CASC2D model.

Results from the study revealed that none of the approaches were able to accurately simulate all storm events. Both the SCS and Snyder lumped unit hydrograph techniques performed well as long as there were gage data for calibration of the sub-basin parameters. However, the distributed model, CASC2D, consistently performed better than or as well as the other techniques over the complete range of storm events tested with regard to peak flows, runoff volume, and hydrograph shape. When there was a lack of sub-basin gage data, CASC2D performed better than the lumped models. Based upon the observed and hypothetical storm events simulated in this study, it can be concluded that

(a) When sufficient sub-basin gaged data are available for calibration purposes, all three watershed hydrologic modeling techniques will produce similar results for design of hydraulic structures.

(b) For limited gage data and for ungaged watershed analysis, the distributed model will provide more realistically shaped hydrographs.

(c) For predictions of sediment yield and transport from watersheds, the distributed rainfall-runoff model will have the advantage over a lumped sub-basin unit hydrograph approach.

(d) The spatially distributed rainfall-runoff technique appears to have other advantages when compared to lumped unit hydrograph methods for purposes of developing a real-time flood forecasting model. This will be especially true when coupled with an accurate updated Geographic Information System (GIS) (rastor or vector) database and with remote data acquisition systems.